PB-245 791

SEMIANNUAL REPORT BY THE COMMITTEE ON MOTOR VEHICLE EMISSIONS OF THE NATIONAL ACADEMY OF SCIENCES TO THE ENVIRONMENTAL PROTECTION AGENCY

National Research Council

Prepared for:

Environmental Protection Agency

January 1972

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PB 245 791

Semiannual Report

by the

COMMITTEE ON MOTOR VEHICLE EMISSIONS

of the

NATIONAL ACADEMY OF SCIENCES

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ENVIRONMENTAL PROTECTION AGENCY

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National Academy of Sciences
Washington, D. C.

NATIONAL ACADEMY OF SCIENCES

OFFICE OF THE PRESIDENT
2101 CONSTITUTION AVENUE
WASHINGTON, D.C. 20418

January 1, 1972

Sirs:

I have the honor to transmit a semi-annual progress report summarizing the work and the findings of our Committee on Motor Vehicle Emissions in accord with the provisions of Section 6 of Public Law 91-604, the Clean Air Amendments of 1970. The distinguished membership of this Committee has given of itself, in full measure, to this task, addressing itself, within the limited time available, almost exclusively to the matter of the feasibility of meeting the standards established, for emissions from light-duty motor vehicles, for model year 1975.

We trust that this report will be of assistance to the Administrator of the Environmental Protection Agency in discharging his responsibilities under that Act. As indicated in the Report, the Committee will continue to address itself to the various responsibilities accepted by the Academy in these regards.

Respectfully yours,

P Handler

Philip Handler
President

The President of the Senate

The Speaker of the House of Representatives

The Administrator of the Environmental Protection Agency

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NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES NATIONAL ACADEMY OF ENGINEERING

2101 CONSTITUTION AVENUE WASHINGTON, D.C. 20418

COMMITTEE ON MOTOR VEHICLE EMISSIONS
OF THE DIVISION OF ENGINEERING

TELEPHONE: 202-961-1621

December 30, 1971

Dr. Philip Handler
President
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Dear Dr. Handler:

On behalf of Dr. Ginzton and the Committee on Motor Vehicle Emissions, I hereby transmit to you the January 1, 1972 semiannual report from the Committee to be submitted to the Congress and to the Administrator of the Environmental Protection Agency.

Sincerely yours,

James E. A. John

James E. A. John
Executive Director
Committee on
Motor Vehicle Emissions

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Semiannual Report

Prepared by

THE COMMITTEE ON MOTOR VEHICLE EMISSIONS,
Division of Engineering, National Research Council,
in accordance with Secti n 202(c) of the
Clean Air Amendments of 1970 and
in partial fulfillment of Contract No. 68-01-0402

between

THE ENVIRONMENTAL PROTECTION AGENCY

and

THE NATIONAL ACADEMY OF SCIENCES

National Academy of Sciences
Washington, D. C.

January 1, 1972

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The study reported herein was undertaken under the aegis of the National Academy of Sciences and its National Research Council with the express approval of the Council of the Academy. Such approval indicated that the Council considered that the problem is of national significance; that solution of the problem required scientific or technical competence and that the resources of the NAS were particularly suitable to the conduct of the project. The institutional responsibilities of the Academy were then discharged in the following manner:

The members of the study committee were selected for their individual scholarly competence and judgment with due consideration for the balance and breadth of disciplines. Responsibility for all aspects of this report rests with the study committee, to whom sincere appreciation is expressed.

Although the reports of study committees are not submitted for approval to the Academy membership or to the Council, each report is reviewed by a second group of scientists according to procedures established and monitored by the Academy's Report Review Committee. Such reviews are intended to determine, inter alia, whether the major questions and relevant points of view have been addressed and whether the reported findings, conclusions and recommendations arose from the available data and information. Distribution of the report is permitted only after satisfactory completion of this review process.

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1. INTRODUCTION

In adopting the Clean Air Amendments of 1970 (Public Law 91-604), which established exhaust emission standards for 1975 and 1976, light-duty vehicles and engines, Congress directed the Administrator of the Environmental Protection Agency (EPA) "to enter into appropriate arrangements with the National Academy of Sciences (NAS) to conduct a comprehensive study and investigation of the technological feasibility of meeting the emissions standards" promulgated in the legislation. The results of this study are to be made available both to EPA and to Congress, with semiannual interim reports and with a final report to be submitted at the completion of the project. Although the Academy's study and investigation is intended to provide information and expert judgment about the full range of technologically related issues pertinent to the automobile emission standards, Congress also contemplated that the Academy's interim reports would play a major role in helping the Administrator exercise his discretion to postpone or not to postpone the applicable deadline if such postponement be requested. In this latter respect, the Administrator, pursuant to Section 202(b)(5)(D), may grant a one-year suspension only if he determines, among other things, that "the study and investigation of the NAS... and other information available to him has not indicated that technology, processes or other alternatives are available to meet (the established) standards."

As a result of the Clean Air Amendments, signed December 31, 1970, discussions were held between EPA and NAS for the purpose of exploring the character of and the most effective way of conducting the study called for in Section 202(c). Pursuant to a contract between EPA and NAS, signed March 10, 1971, and retroactive to February 1, 1971, a strategy committee was formed by NAS in March 1971 to develop a proposed work statement and to suggest members for the Committee on Motor Vehicle Emissions. The initial Committee membership was selected by the National Academy of Sciences in April 1971, with other members added in later months. Committee membership is listed in Appendix A along with the members of the Committee staff. A work statement and contract proposal were submitted by the Academy to EPA in May 1971. A contract for $612,175 was signed by EPA on August 2, 1971. The first meeting of the Committee took place June 16, 1971 and subsequent meetings were held monthly.

According to the work statement, (Appendix B) the Committee on Motor Vehicle Emissions is to conduct a many-faceted study of the technological feasibility of meeting the motor-vehicle emission standards prescribed by the Administrator of EPA, as required by Section 202 of the Clean Air Act, as amended. Technological feasibility as defined in the work statement, "includes the ability within the automobile industry or elsewhere to:

1. Design an engine, control system, or device capable of meeting the statutory emission standards using fuels that are or could be available;

2. Mass produce such an engine, control system, or device;

3. Maintain such an engine, control system, or device so that it will continue to meet the statutory emission standards with safety for a period of five years or 50,000 miles of operation, whichever is shorter."

It was agreed that the study of technological feasibility will include an investigation of the anticipated costs to be incurred and the estimated time for the design, development, and mass production of an engine, control system, or device capable of meeting the standards. Also to be included is a study of the estimated annual costs incurred in maintaining such an engine, control system, or device so that it will meet the emission standards for five years or 50,000 miles, whichever is shorter. Finally, should the Committee conclude that the attainment of emission standards on the schedule provided in Section 202(b)(1) of the Clean Air Act is not technologically feasible, the Committee is to determine technologically feasible interim emission levels to assist the Administrator in exercising his responsibilities under Section 202(b)(5) of the Act.

It was decided by the Committee early in its deliberations that, in order to obtain the necessary technical information upon which to base a responsible judgment, it would be necessary to form a series of panels of consultants dealing with principal topical areas and composed of recognized experts in the relevant fields. Seven Panels have been formed as shown in Table 1.1. Membership of the Panels is given in Appendix C.

Under the Clean Air Amendments, at any time after January 1, 1972, any manufacturer may file with the Administrator an application requesting the suspension for one year of the regulations applicable to emissions of carbon monoxide and hydrocarbons from light-duty vehicles for the 1975 model year. At any time after January 1, 1973, requests can be made for a similar one-year suspension of the regulations applicable to oxides of nitrogen for 1976 model year light-duty vehicles.

In order to provide maximum assistance to the Administrator in the possible exercise of his discretion to suspend for one year the deadline date for meeting the 1975 standards, and in view of the limited time available from the formation of the Committee to the January 1, 1972, interim report date, it was decided to concentrate the initial work of the Committee and the Panels on issues pertaining to the technological feasibility of meeting the standards applicable to 1975 model year cars.

Table 1.1

Panels of the Committee on Motor Vehicle Emissions

Panel 1:	Emission Standards
Panel 2:	Testing, Inspection, and Maintenance
Panel 3:	Emission Control Systems (for spark-ignition internal-combustion engines)
Panel 4:	Alternate Power Sources
Panel 5:	Manufacturing and Producibility
Panel 6:	Driveability
Panel 7:	Atmospheric Chemistry

It is recognized that emission-control systems for 1975 vehicles cannot be completely divorced from those that must be provided for vehicles that will have to meet the 1976 standards (see Section 3.4). Some degree of compatibility between the two must be provided. Nevertheless, because a decision on the technological feasibility of meeting the 1975 standards may have to be made within 60 days of January 1, 1972, the main emphasis of this report will be on the technological feasibility of the emission standards applicable to 1975 model year vehicles.

The first Panels in operation were Emission Standards; Testing, Inspection, and Maintenance; Emission Control Systems (for spark-ignition internal-combustion engines); Driveability; and Manufacturing and Producibility.

The five Panels mentioned above began operation in July 1971, and have been active since that time. Many of the Panelists have devoted virtually full-time effort to the work of the Committee since July. Panel visits have been made to all the domestic automobile manufacturers, to EPA laboratories in Ann Arbor, Ypsilanti, and Research Triangle Park, to the U. S. Army Tank-Automotive Command, many catalyst suppliers, manufacturers of various testing equipment, the California Air Resources Board, and to other groups engaged in emission-control research and development.

Extensive information has been obtained from a questionnaire sent on September 27, 1971, to all five domestic automobile manufacturers and to all sixteen foreign automobile manufacturers exporting a significant number of cars into the United States. A copy of this questionnaire and lists of those to whom it was sent and those who responded are included in Appendix D. The high degree of detail of the replies was very gratifying. Most of these documents were received in time for the Committee and pertinent Panel members to read them prior to a further meeting held in Washington, D. C., on October 25-27, 1971, between the Committee and the manufacturers. (Those who attended are so designated in Appendix D). At this meeting the Committee and Panel members questioned the manufacturers individually with respect to their responses to the questionnaire and sought the latest information with regard to the technological feasibility of meeting the requirements of the Clean Air Act of 1970. In addition, many Committee and Panel members made personal contacts with the automobile manufacturers and others in order to clarify points they felt could be important in making their evaluation. Further, the Committee issued a statement (Appendix E) on September 21, 1971, inviting the submission of information on behalf of the public concerning the technological feasibility of meeting the requirements of the Act. This statement was sent to over 700 organizations and individuals, including major newspapers, wire services, general science magazines, engineering and industry publications, and environmental groups and publications.

The statement was also placed in the Federal Register of December 3, 1971. But, as yet, the number of direct responses has been disappointingly small.

In the limited time that the Committee has had available since its creation in the summer of 1971, all possible efforts have been made to secure the material and information needed to reach the judgments called for in the legislation. Perforce most of the pertinent data required were in the possession of the various concerned manufacturers, primarily the automobile companies. Necessarily, therefore, the analyses to follow rest primarily upon the information received from those sources.

However, recognizing the possible bias that this might introduce the Committee has endeavored, in various ways, to ensure that the information obtained from the companies is complete, accurate and timely. Members of the Committee and its Panels, along with special consultants, have interrogated working-level company technicians and engineers, have personally examined laboratories and testing facilities and have reviewed intensively the techniques employed by the companies in analyzing their experiments and data. In addition, the Committee has utilized certain information provided by EPA as well as data gathered in the hearings conducted by EPA in May 1971.

The Committee's work in all of these respects will continue in the coming year, but, as of now, it is the judgment of the members that the information it has received is sufficiently reliable and comprehensive as to constitute an appropriate basis for the judgments it has reached and which are set forth in this report. In the coming months, the Committee will continue its investigation so as to ensure that the most complete and sound scientific information is available both for its own purposes and for the use of EPA and the Congress.

The emphasis in this report is on the 1975 standards, for the reasons noted earlier. The Committee's study and investigation will continue as it expands its inquiry into areas pertinent to the 1976 standards.

2. STANDARDS AND TESTING

2.1 Introduction

According to Section 202 of the Clean Air Amendments of 1970, the Administrator of EPA is required to prescribe emission standards for light-duty motor vehicles and measurement techniques on which such standards are based. Pursuant to Section 202(b)(1)(A) such standards require that the emissions of carbon monoxide and hydrocarbons from light-duty vehicles manufactured during or after model year 1975 shall be reduced by 90 percent from those required of 1970 vehicles; also, emissions of oxides of nitrogen from light-duty motor vehicles manufactured during or after model year 1976 are to be 90 percent below the average of those actually measured from 1971 model year light-duty vehicles.

Standards and test procedures were promulgated by EPA and are contained in the Federal Registers of November 10, 1970, and July 2, 1971. The 1975 model year standards are:

0.41 grams per vehicle mile for hydrocarbons,

3.4 grams per vehicle mile for carbon monoxide,

and 3.0 grams per vehicle mile for oxides of nitrogen.

For 1976 model year vehicles, exhaust emission standards are:

0.41 grams per vehicle mile for hydrocarbons,

3.4 grams per vehicle mile for carbon monoxide,

and 0.4 grams per vehicle mile for oxides of nitrogen.

The Clean Air Act Amendments further call for vehicle compliance with these standards for the useful life of the vehicle, defined in the Law as five years or 50,000 miles, whichever occurs first.

Testing to ensure compliance with these standards is to be conducted in three stages. First, prototype models of each engine class are to be tested prior to issuing a "certificate of conformity." Next, production-line testing is contemplated to ascertain whether production models conform with the regulations with respect to which a certificate has been issued. Finally, provision is made for testing emissions and for continuing compliance while a vehicle is in actual use.

2.2 Testing for the Certificate of Conformity

The test procedure for determining whether a certificate of conformity may be issued for 1975 and later model year vehicles consists of emission and 50,000-mile durability tests with a limited amount of maintenance on a fleet of vehicles representing each engine class for each vehicle manufacturer. As now defined by EPA this procedure permits one engine tuneup but no emission-control system replacements during the 50,000-mile durability test and requires that emissions be less than the standard for 50,000 miles.

The emission test, as described in the Federal Register of July 2, 1971, is designed to determine hydrocarbon, carbon monoxide and oxides of nitrogen mass emissions while simulating an average trip of 7.5 miles in an urban area. Each emission test consists of a twelve-hour wait at 70 degrees F, a cold-engine startup, a continuous sequence of different driving modes similar to actual driving over a 23-minute route and a 10-minute shutdown followed by a hot-engine restart and a repeat of the first 505 seconds of the 23-minute cycle. Diluted exhaust emissions are collected continuously using a constant volume sampler. Emissions collected during the first 505 seconds from cold start are collected in one bag, those from the remainder of the 23-minute cycle in a second bag, and the emissions from the hot-restart phase collected in a third bag. The contents of the three bags are then analyzed and weighted in accordance with the EPA test procedure to attain the final mass emissions, in grams per mile.

The technology of testing according to the prescribed procedures requires expensive equipment and instruments. At the present, the equipment and procedures are more characteristic of a laboratory than of an industrial production line or state inspection station. The estimated cost of equipping a single test cell with the necessary equipment to perform a complete vehicle test according to the prescribed procedure is approximately $100,000. This includes the dynamometer, constant volume sampling equipment, instrumentation for analyzing the sample bags for the three pollutants, and the other required equipment. Such a test would require two people per cell and would consume approximately one hour, following the twelve-hour wait at 70 degrees F. The time required and equipment needed for this test make it difficult to conceive of its use for production testing of every vehicle or for service testing or vehicle-inspection programs for vehicles in use.

2.3 Production-Line Testing

To satisfy the requirements of Section 206, testing procedures for new production-line vehicles will be needed. Consideration of possible effective procedures immediately raises three significant questions:

(1) How many vehicles should be tested?

(2) What test procedures should be used?

(3) Should every vehicle tested meet the prescribed emission standards?

While these questions are not independent, we shall discuss them in sequence.

Given the large number of vehicles produced, testing a sample of new vehicles by the full cold-hot CVS* test can determine the emission characteristics of the vehicle population as precisely as is necessary. Sample testing and statistical analysis for quality-control purposes is a thoroughly developed and accepted procedure in industrial operations. There is no reason why testing of samples of new vehicles according to the certification procedure cannot be used to establish with sufficient accuracy the average emission characteristics and the probability of occurrence of vehicles having high emissions. A simple test on all vehicles may make possible the detection of some individual improperly manufactured cars that are very high emitters. Unfortunately, no such short test is available at present that correlates well with the complete test.

As will be described, the technology of emission-control systems for conventional reciprocating spark-ignition internal-combustion engines is complex. Control of the quality of manufacturer and assembly of the components will have to be thorough if these systems are to function effectively for an extended period. Laboratory models of the systems that are being developed are constructed and maintained to their highest level of performance by highly qualified personnel; variations from the optimum configuration tend to lead to degraded performance and increased emissions. Not only will the production quality of the emission-control systems need to be precisely controlled, but also new diagnostic techniques for detecting and correcting the occasional defective production vehicle must be developed. These are the responsibilities of the manufacturer, but strict enforcement of the production-line tests and standards will be necessary. Production-line emission-control testing should therefore be concerned with assuring that the manufacturer has met his responsibility to produce an effective emission-control system on his new vehicles.

Due to the nature of mass-production processes, emission-control systems will not be precisely identical. As far as contribution to air pollution is concerned, it is the total emissions from all emitting vehicles that are of consequence. In other words, it is the average emissions that affect air quality, where average emissions refer to the total emissions divided by the number of vehicles. Therefore, the Committee believes

*Constant volume sampling test described previously.

it necessary that the averaged emissions from all vehicles meet the emission standards over the vehicle lifetimes.

As discussed below, it is likely that periodic inspection of emission-control systems in used vehicles may be instituted, and the purchaser of a new vehicle must be assured that it is not so defective as to be incapable of passing such tests as are likely to be used. Therefore, new vehicles whose emissions are significantly higher than the standards must be corrected by the manufacturer prior to sale, even though their contributions to total emissions may be minor. It will therefore be necessary, through statistical quality control and diagnostic testing on all new vehicles, to put limits on vehicle emissions.

2.4 Surveillance Testing of Used Vehicles

It is contemplated that there will be emission testing of a sample of vehicles in service, as maintained by their owners, to determine their emissions. The results will be compared with the standards and the durability tests run during compliance. The responsibility for correcting vehicle emissions, if found necessary, will lie with the manufacturer, provided the owner has complied with the terms of a legally acceptable warranty concerning maintenance of the emission-control system.

2.5 State and Local Inspection of Used Vehicles

Under the Law EPA is to encourage state periodic inspections of used vehicles where necessary and feasible if the Administrator of EPA finds that a suitable test is available. New Jersey and California are about to begin inspections with a simple idle test that correlates well with the 7-mode test currently used for vehicle certification; this idle test does not, however, correlate with the EPA test procedure to be used for 1975 model year vehicles. Descriptions of the various test procedures are given in Table 3.1.

In 1975 and later model year cars, one of the primary modes of emission-test failure is expected to be associated with the cold-start portion of the test; this would not be caught by present idle tests. The presently available emission performance inspection tests do not correlate well enough with the CVS-CH test required for certification of 1975-1976 vehicles to show great promise. Until a suitable test is available, a functional inspection to determine whether the control system is present and operational would have to be used.

3. EMISSION-CONTROL TECHNOLOGY

3.1 Background

The vast majority of the engines used in the 1975 model year vehicles will inevitably be conventional reciprocating spark-ignition internal combustion engines. Wankel rotary combustion and stratified-charge spark-ignition engines* may eventually have a place in the automotive market, as may alternative types of power plants. However, for 1975 production, the lead times of two years or more required to design, erect and equip modern mass-production facilities, as described in Section 5, are such that irreversible decisions on the basic engine and control system must be made by mid-1972. These alternatives to the conventional engine are at an early stage of development and need extensive testing and evaluation before rational decisions can be made. As a result, the Committee, in evaluating the technology available to meet the 1975 emission standards, has decided to concentrate on the reciprocating spark-ignition engine, deferring its studies of alternate power sources to the future (see Section 9). Though engine modifications to reduce emissions are likely to be incorporated, the basic geometry and operation of the engine will be similar to what it is today.

Emissions from uncontrolled automobiles, as manufactured prior to 1968, came from the crankcase blowby gases, fuel evaporation from the fuel tank and carburetor, and the engine exhaust. The crankcase and evaporative losses have now been controlled. The emissions from the engine exhaust are a consequence of the details of the combustion process occurring inside the engine cylinder. Hydrocarbons (HC) and carbon monoxide (CO) result from incomplete combustion of the fuel-air mixture; oxides of nitrogen (NO_x) form in the high-temperature burnt gases as the combustion process proceeds. Indeed, it was due to this fact that when 1968 standards were set for CO and HC in California, the NO_x levels in the atmosphere rose because of the adjustments made to reduce only CO and HC.

As a result of the Federal Emission Control Program, commencing in 1968, considerable emission control on new vehicles has already been achieved by engine modifications and improvements in engine design (Table 3.1). It is unfortunate that the automobile industry did not seriously undertake such a program on its own volition until subject to this governmental pressure and general recognition of the role of automobile emissions in the generation of smog in California. This long lag period together with the growth in automobile sales gave rise to the sense of urgency expressed in the Clean Air Amendments.

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* Described in Section 3.7

Exhaust-emission standards measured in grams of pollutant per mile of vehicle travel were first introduced for HC and CO on 1968 model year vehicles and have since been progressively tightened. As understanding of factors affecting vehicle emissions has increased, the test procedure has been changed to determine more accurately the automobile's contribution to total urban emissions. The different test procedures used are described briefly in Table 3.1. Note that each emission standard is associated with a particular test procedure and that, though standards for 1972 are stricter than those for 1970, the values are higher as a consequence of the different tests used.

Figure 3.1 shows the percentage reduction in exhaust emissions represented by these standards. The exhaust-emission standards are compared with average exhaust emissions from uncontrolled vehicles measured with the 1972 test procedure. This figure shows that for 1972 model year vehicles, about 80-percent control of HC and 70-percent control of CO are now required.* With control of crankcase emissions and fuel evaporation included, about 85-percent reduction in total HC emissions is being achieved. Federal NO_x standards start in 1973, and about 50-percent control will be required. In California, about 30-percent control of NO_x is now required on new vehicles sold there.

The substantial reductions in HC and CO exhaust emissions already achieved have resulted from engine-design modifications and changes in engine-operating conditions. These include adjustments to the carburetor to provide leaner fuel-air mixtures and improved mixture uniformity, controlled heating of the intake air, increased idle speed, retarded spark timing, reduced engine compression ratio, and improved cylinder head design. In some systems, air injection into the exhaust manifold has been used to burn up a fraction of the HC and CO emissions in the exhaust.

The federal emission standards for NO_x in 1973 and 1976, and for HC and CO in 1975 given in Table 3.1 will require new control techniques. Control of HC and CO emissions to the 1975 standard levels appears to be unattainable through engine modifications of the type used to date. With conventional engines, HC and CO emissions from the engine itself are much higher than the 1975 standards under all practical operating modes. Special reactors or converters located in the exhaust system will be required to burn up the emissions from the engine. NO_x control to below 3 g/mile will require some exhaust-gas recycling to the engine intake to reduce peak burnt gas temperatures. Both these new control techniques have a substantial impact on engine operation and performance.

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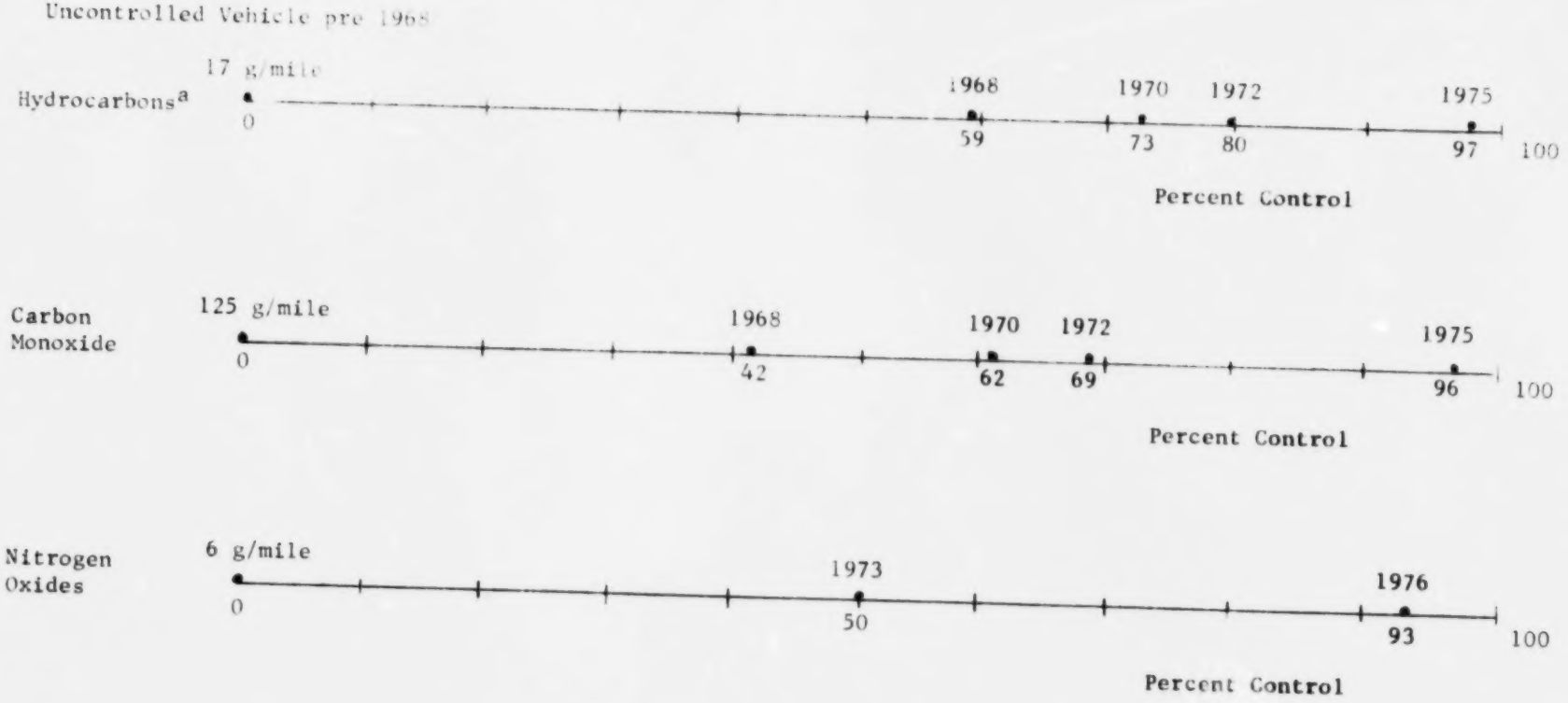
* 80-percent control requires a five-fold reduction in emissions; 70-percent control about a three-fold reduction.



a Blowby HC emissions (about 4 g/mile) have been 100-percent controlled since 1963; evaporative HC emissions (about 3 g/mile) will be 95-percent controlled with 1972 model year cars.

b All standards have been converted to values corresponding to CVS-C Test.

Figure 3.1. Percentage Reduction in Exhaust Emissions Represented by the Federal Standards [b]

Table 3.1

Federal Emission-Control Requirements for Light-Duty Vehicles

Model Year	Pre 1968*		1968	1970	1971	1972	1973	1975	1976
Test Procedure	FTP	CVS-C	FTP	FTP	FTP	CVS-C	CVS-C	CVS-CH	CVS-CH
Emissions, grams/mile									
Hydrocarbons	10	17	3.4	2.2	2.2	3.4	3.4	0.41	0.41
Carbon Monoxide	77	125	35.0	23.0	23.0	39.0	39.0	3.4	3.4
Nitrogen Oxides	4-6	6	NR	NR	NR	NR	3.0	3.0	0.4
Evaporative losses grams/test	40		NR	NR	6.0	2.0	2.0	2.0	2.0

NR - No requirement

*Uncontrolled vehicle except for crankcase blowby control.

Test Procedures Used to Measure Emissions

FTP — Federal Test Procedure - The driving cycle is the California 7-mode cycle repeated nine times. Pollutant concentrations in the exhaust are analyzed continuously throughout the 16-minute test. Concentrations in each mode are multiplied by weighting factors to give grams/mile. This is not a true mass emissions measurement.

CVS-C — Constant Volume Sampling Procedure - This is a cold start mass emissions test. The vehicle stands at constant temperature for 12 hours at 70 degrees F before engine startup. The driving cycle is a 23-minute, 7.5-mile non-repetitive pattern. A constant fraction of the exhaust flow is collected in a bag, and concentration measurements at the end of the test give true mass emissions in grams/mile.

CVS-CH — Constant Volume Sampling Procedure - This is a cold-hot start weighted mass emissions test. The vehicle stands at constant temperature for 12 hours at 70 degrees F before engine startup. The driving cycle is the 23-minute pattern used in CVS-C. After a 10-minute shutdown, the engine is restarted and the first 505 secon of the driving cycle repeated. A constant fraction of the exhaust flow is collected: the first 505 seconds in a "cold transient bag"; the ne. 364 seconds in a "stabilized bag"; and the repeat 505 seconds in a "hot transient bag." Emissions in cold and hot transient bags are weighted 0.43 to 0.57 respectively, and added to emissions in stabilized bag to give true mass emissions.

The effectiveness of these new control systems depends to a large extent on how well the individual components in the system have been integrated. It must be remembered that typical vehicle driving is a continuous sequence of different operating modes--engine startup, idle, acceleration, cruise, deceleration, and so forth. To obtain satisfactory engine and vehicle performance over this wide range of modes, the air flow into the engine, the air-fuel ratio, and spark timing are all varied as engine loads and speeds change. The engine must also start and operate satisfactorily over the complete range of ambient temperatures, humidity, and altitude (which affects air density and hence fuel metering) found throughout the United States.

The federal emissions test that has been promulgated by EPA to certify prototypes of the 1975 production vehicles, as described in Section 2 and Table 3.1, incorporates a driving cycle that includes the common driving modes. The overall emission-control system must be optimized to operate effectively over the entire range of engine conditions covered in the test to achieve average HC and CO emissions below the 1975 standards.

The cold-engine start and first few minutes of the test before the engine fully warms up prove to be especially important. In current automobile engines, a choke is used to enrich the fuel-air mixture when the intake manifold is cold and fuel vaporization is poor. This enrichment is necessary to ensure that enough fuel is vaporized to provide a combustible mixture near the spark plug and achieve safe and satisfactory vehicle operation. It results in high engine HC and CO emissions during the warm-up phase because not all this fuel can be fully burnt. Moreover, the reactors in the exhaust, which are provided to burn up the HC and CO emissions from the engine itself, also must warm up before they become effective for typical 1975 control systems. It turns out that HC and CO emissions during the first two minutes of the test are greater than HC and CO emissions during the last 21 minutes. Thus, the importance of adequate emission control during the warm-up phase is obvious.

3.2 Proposed 1975 Emission-Control System

Although many possibilities exist, in principle, for reducing emissions from a reciprocating engine and for removing such emissions prior to the exhaust gas entering the air, the Committee finds that most manufacturers have selected systems and components that are similar to each other. In reviewing the available technology for reduction of emissions, the Committee and its Panels, after considerable study of the alternatives, believe that the basic choice of components made by the manufacturers throughout the world is reasonable, and that no other concepts have been proposed that offer greater potential for meeting the 1975 requirements in 1975.

Further, the basic configurations needed for the 1975 systems must reach final design stage by mid-1972 to permit system testing, endurance testing of components, modifications and corrections, and to assure that the final systems are acceptable to the public.

As will be discussed in the subsequent sections of this report, numerous advances in emission controls have been suggested and tested. To make our discussion more coherent, we shall describe the principal components of the suggested systems and comment on their state of development and reliability.

3.2.a Exhaust-Gas Recycle

Exhaust gas recycle (EGR) will be used to diminish NO_x emissions. The recycling of 10-20 percent of the exhaust flow to the intake manifold is used to dilute the fresh fuel-air mixture entering the engine with a largely inert gas. The additional thermal capacity of the recycled exhaust lowers peak burnt gas temperatures inside the cylinder, which reduces the formation of nitrogen oxides. Some losses in vehicle performance result. The fraction of the exhaust recycled must be carefully matched to engine conditions, otherwise serious degradation in vehicle-performance characteristics, such as engine stall, stumble, and rough operation, can occur. A valve activated by the intake-manifold vacuum or throttle position is proposed to control the recycled flow. The use of EGR generally requires that the fuel-air mixture be enriched to maintain satisfactory engine operation. This enrichment increases the HC and CO emissions from the engine, which must then be burnt up in a thermal reactor or catalytic converter, and it increases the fuel consumption.

3.2.b Secondary Air System

The use of EGR and richer fuel-air mixtures requires the addition of air to the exhaust flow before the engine HC and CO emissions can be burnt up in a reactor or converter. An engine-driven air pump drives this air through a distribution manifold into the exhaust ports.

3.2.c Thermal Reactor

A thermal reactor is an enlarged exhaust manifold that bolts directly onto the cylinder head. Its function is to promote rapid mixing of the hot exhaust gas with the secondary air and retain the gases at a high enough temperature for sufficient time to burn up most of the HC and CO. To achieve rapid warm-up after engine start, a thin steel liner acts as the core of the reactor inside a cast iron outer casing with heat losses held to a minimum. The fuel-air mixture in this case is enriched so that the chemical energy released inside the reactor in the burn-up process holds the core at temperatures of 1600-1800 degrees F.

3.2.d Oxidizing Catalytic Converter

Oxidation of the HC and CO in the exhaust gas can be accomplished by means of catalysts at temperatures lower than those in a thermal reactor. A catalytic converter can be placed farther from the engine than a thermal reactor, and can maintain its effectiveness without mixture enrichment to increase the chemical energy in the exhaust. As a consequence, the fuel-economy penalty is lower. The catalyst used is made up of a small mass of active material such as noble metal or a combination of transition and non-transition metals, deposited on thermally stable support materials such as alumina. To prevent loss in catalytic activity due to mechanical damage, small spherical pellets or a honeycomb (monolithic structure) have been found the most suitable geometries. The catalyst is contained in a metal casing designed to direct the exhaust flow through the catalyst bed.

For high conversion efficiency throughout the test cycle, the catalyst must attain its "light-off" temperature* as soon as possible after engine startup. Considerable development work has therefore been done to reduce the density of the support material and increase the surface area of the active components. To maintain high catalytic activity, the fuels employed need to be low in concentration of various catalyst poisons such as lead, phosphorus, and sulphur. For most catalysts, the relative conversion efficiency is independent of exhaust-gas compositions over a wide range of HC and CO concentrations.

3.2.e Major Engine Modifications

More precise fuel metering following changing engine conditions is required to maintain effective emission control. Fuel-air mixture preparation during the engine warm-up phase is especially important. The exhaust-gas composition and temperature at entry to the thermal reactor or catalytic converter must be matched to reactor or converter performance, which requires more accurate fuel-air-ratio control. Fuel and air distribution between different cylinders of the engine must be made more uniform. The use of EGR further complicates the problem of mixture preparation. Good mixing and distribution are required to maintain adequate vehicle performance. Improved carburetors are being developed to satisfy these requirements. Alternative fuel-metering concepts, such as fuel injection, that may offer better control are also being explored. Compensation for air-density changes with altitude will probably be required. Greater metering accuracy during engine startup and warm-up is also necessary. Power chokes have been incorporated to make choke operation more reliable. The choke is being released earlier in the engine warm-up phase to reduce HC and CO emissions. Intake manifolds are being redesigned to improve fuel, air, and recycled exhaust-gas distribution between cylinders. Quick heat intake manifolds are also

*The temperature at which the catalyst effectively oxidizes HC and CO emissions.

being developed to reduce emissions during the engine warm-up phase. A part of the intake with low thermal inertia is directly heated by the exhaust gas to achieve good fuel vaporization before the engine is fully warmed up. As a consequence, the fuel-air mixture can be leaned out sooner after engine startup.

Ignition-system malfunction due to wear and inadequate maintenance is a common cause of increased HC emissions in current vehicles. For 1975 vehicles, electronic and inductive ignition systems have been developed that will improve reliability in customer use. Control of spark timing can be made more easily and will be used to reduce HC and NO_x emissions. Spark-retard during engine warm-up will also be used to increase exhaust-gas temperatures and hence reduce the time required for reactor and converter to become effective.

Cylinder-head modifications are made primarily to maintain adequate vehicle driveability when EGR is used to reduce NO_x emissions. While optimized surface-to-volume ratio gives some reduction in HC emissions, the major gain is improved combustion characteristics. For systems using a catalytic converter, exhaust ports and manifolds and exhaust pipes are being modified to promote rapid mixing of exhaust gas and secondary air, and to reduce heat losses to a minimum.

3.2.f Control-System Integration

Most of the complete emission-control systems that show some promise of approaching the 1975 emission standards require the following: improved carburetor performance, fast-acting and more accurate choke, inductive or electronic ignition system with modified timing, exhaust-gas recycle, secondary air pump with air injection into the exhaust ports or manifolds, and an oxidizing catalytic converter to complete the burn-up of HC and CO. When its performance is optimized, this system can achieve very low HC and CO emissions once the catalyst attains its light-off temperature. However, unless additional controls are used, the catalytic converter warms up too slowly to adequately control emissions when the engine is cold. The rich fuel-air mixtures used while the engine is warming up result in high exhaust HC and CO emissions.

Two main approaches are being developed with the objective of achieving greater emission control during the engine-warm-up phase. In one approach, the conventional exhaust manifold is replaced with a small-volume thermal reactor located upstream of the catalytic converter. The reactor is designed so that, very quickly after engine start, it will reach temperatures at which HC and CO will be burnt up. The combustion of some of the HC and CO raises the temperature of the gas leaving the reactor. Consequently, the catalyst bed heats up more rapidly. Once the catalyst reaches its operating temperature, the reactor and catalyst share the burn-up duty, with the catalyst bed playing the major role.

The other approach attempts to lean out the fuel-air mixture earlier in the engine warm-up phase by modifying the intake manifold. A quick heat manifold design is used, in which part of the intake is heated rapidly by the exhaust gases to obtain better fuel vaporization. The need for fuel-rich mixtures is obviated during the period a conventional intake would take to warm up, and HC and CO emissions are substantially reduced. Once the catalyst is warmed up, HC and CO emissions are brought down to very low levels.

Emission-control systems must also be designed to withstand types of vehicle operation other than those included in the emission test cycle. High-speed cruise, maximum acceleration, long-duration descent along a downgrade, and operation with a vehicle overload may place extra demands upon the emission-control system. Some manufacturers plan to install cut-out devices that will bypass some or all the control-system components in these operational modes in order to preserve the system's functional integrity during normal urban driving conditions. Thus a great variety of vehicle uses, and even abuses, must be withstood without damage to the emission-control system if it is to function successfully throughout the lifetime of the vehicle.

3.3 Current Stage of Development

3.3.a Emissions at Low Accumulated Mileage

The emission-control systems described in Section 3.2 have been under intensive development on experimental vehicles. This development includes both improvement in performance and durability of individual components, and optimization of the interaction between the many components to achieve the most effective overall emission control. To allow for degradation in control-system effectiveness (especially catalyst deterioration), and for slippage in emission control when moving from experimental to production vehicles, most manufacturers have set low-mileage emission targets for their experimental vehicles that are below the standards. Furthermore, even these targets are based on the assumption by manufacturers that standards need to be met only on the average, and not by each vehicle. In the past, system deterioration and slippage in the transfer to production vehicles have been significant. Manufacturers' development efforts are concentrated first on achieving low-mileage emission targets with systems having mass-production potential and subsequently on testing the durability of system components over extended mileage.

A number of uncertainties still exist concerning the definition of compliance with the law, which affect the choice of values of these low-mileage emission targets. These uncertainties are allowable maintenance during the 50,000-mile certification procedure, the testing of vehicles at the end of the assembly line, and whether all vehicle emissions or only the average of vehicle emissions, as defined in Section 2.3, must meet the standards during the vehicle's useful life.

The present durability-testing procedure is to allow maintenance comparable to the average that vehicles receive in customers' hands. The question whether catalyst replacement can be regarded as part of this normal maintenance is particularly important since, as will be described in more detail later, catalyst deterioration is a major problem with the contemplated 1975 emission-control systems.

If the full recommended customer maintenance is not allowed during the certification procedure, then deterioration in emission control over the 50,000 miles will be greater. EPA has not yet determined whether this option is open to manufacturers.

An end-of-assembly-line emissions test, as distinct from a test intended to ensure effective manufacture and assembly, might require a further lowering of these low-mileage emission targets. The combination of production tolerances on piece parts and subassemblies will inevitably result in a distribution of emissions about the mean, some vehicles emitting more than the mean value, some less. The requirement that emissions from all, or almost all, production vehicles be below the standard would be a much more severe requirement than the requirement that only the average emissions of all production vehicles be below the standard.

Typical manufacturers' low-mileage emission targets are shown in Table 3.2. Values vary somewhat depending on manufacturers' past experience and judgment. These targets are currently being set at about 50 to 60 percent below the emission standards to allow for a 10-20 percent increase in emissions as the control system is transferred from experimental to production vehicles, for a factor of about 2 deterioration in HC and CO emission control over 50,000 miles (primarily from the decreasing effectiveness of the catalyst), and for deterioration in the EGR system due to plugging of the line and valve with deposits. The low-mileage emission targets set at about 50 to 60 percent below the standards are based on the assumption that only the average emissions of production vehicles must meet the standards, and that recommended customer maintenance (including catalyst replacement if necessary) will be allowed during the 50,000-mile certification testing.

Table 3.2 presents a summary of data on the best emissions results attained to date* supplied to the Committee by the automobile-manufacturing industry. The emissions measurements summarized in the table were done on vehicles equipped with the prototype versions of each manufacturer's 1975 control system. They represent the average of several tests on each vehicle. The mileage accumulated on these vehicles and systems is a few thousand miles at most. Appendix F gives the emissions measured from each manufacturer's best car. The data from Appendix F were used to compile Table 3.2. These results show that, at the present stage of development, most manufacturers have been able to achieve emission levels close

*October 15, 1971

Table 3.2

Low-Mileage Emission Targets and Measurements[a]

	Emissions, grams/mile		
	HC	CO	NO_x
1975 Standards	0.41	3.4	3.0(1.5)[b]
Low-mileage targets[c]	0.19	1.5	1.9(0.9)
Major U. S. Manufacturers			
Single best car (car C from Appendix F)	0.13	1.9	1.3
Average of each manufacturer's best car (average of cars A, B, C, D, E from Appendix F)	0.21	2.8	2.2
Range of best-car emissions	0.13-0.31	1.9-3.7	1.2-4.5
Range of emissions from one manufacturer's development fleet[d]	0.2 -0.9	3-12	0.9-1.4
Foreign Manufacturers			
Average of each manufacturer's best car	0.33	3.7	1.7
Range of best-car emissions	0.10-0.63	2.4-5.8	0.6-2.5

[a]The data are as of October 15, 1971. The emission data are the average of several tests on laboratory-engineered vehicles at low mileage using the 1975 test procedure except where indicated in Appendix F. More detailed data are given in Appendix F.

[b]Values in parentheses are applied to proposed California 1975 standards.

[c]These are typical values; targets vary between manufacturers depending on past experience and judgment. Certain assumptions about production vehicles affect these targets.

[d]Typical development fleets contain 5-10 vehicles, with different-size engines and different drive transmissions. Control systems are at different stages of development.

to the 1975 standards on laboratory-engineered vehicles at low mileage. However, it will be shown in Section 3.3.b that vehicle emissions increase steadily with accumulated mileage, the main reason being the deterioration of catalyst performance.

One U. S. manufacturer with one vehicle has come close to the listed low-mileage emission targets. The major U. S. manufacturers each have one or a few vehicles with emissions between these targets and the standards. Better HC-emission control has been achieved than CO-emission control; the average of United States manufacturers' best vehicles shows HC low-mileage emissions 49 percent below the 1975 standard and CO low-mileage emissions 18 percent below the 1975 standard.

Table 3.2 also shows the range in emissions in one U. S. manufacturer's 1975 development fleet. These fleets are typically five to ten cars, each equipped with the basic elements in the 1975 emission-control system. These vehicles are usually different models in the manufacturer's product line, with different engines and drive trains. Other manufacturers' fleets show a similar range in emissions. These results indicate that the same emission-control system applied to vehicles with different engines and drive trains shows a spread in low-mileage emissions of a factor of 2 to 3 above and below the mean. This spread is due both to the different stages of development of each of the experimental vehicles and to different individual vehicle reactions to the control-system components.

The emission levels achieved by foreign automobile manufacturers shown in Table 3.2 also indicate that considerable progress has been made. The magnitude of their emissions research and development efforts is generally less than that of U. S. manufacturers and appears to depend on the importance placed on retaining their share of the U. S. market. Availability of test equipment and trained manpower have also been stated to be limitations on the programs of foreign manufacturers. The averages of emissions from each manufacturer's best-effort vehicles are higher than the corresponding averages of U. S. manufacturers' best efforts. The spread in emissions from these best-effort vehicles is also greater. It is clear that some of these manufacturers have not progressed to a stage at which they can evaluate their position in relation to the 1975 standards with any confidence. In general, the Committee judges that foreign manufacturers have not achieved the degree of emission control achieved by the major United States manufacturers.

The results summarized in Table 3.2 also show that the NO_x emission control required by federal standards in 1975 (3 g/mile) appears to be within the capability of these laboratory control systems. However, the proposed California NO_x 1975 standard of 1.5 g/mile* may not be

*This standard is for all production vehicles and not just the average emission.

feasible and may affect manufacturers' ability to hold HC and CO emissions at levels close to the 1975 federal standards. The potential of these control systems to achieve greater NO_x reductions is explored more fully in Section 3.4.

At this point, it must be stressed that emissions measurements on a single vehicle should be interpreted with caution. There is a significant variation in results when the same vehicle is tested several times with the same test equipment, due to changes in control-system performance and errors and inadvertent variations in the test procedure. Variations in emissions of $\pm$ 50 percent about the average value are not uncommon. Thus, conclusions can be drawn only from the average of several tests on any one vehicle. Currently available data are also insufficient for determination of whether excellent performance with the control system on one vehicle can be achieved on another vehicle with different weight, engine, and drive train. The effectiveness of a given system on a manufacturer's entire product line can, at present, only be inferred.

Data submitted to the Committee and its Panels by research and development groups outside the automobile industry attempting to achieve emission control to the 1975 standards with reciprocating spark-ignition engines have not indicated the achievement of better emissions control. Moreover, few of these groups have attempted to test and demonstrate the durability of their systems over extended mileage.

3.3.b System Durability

Before these laboratory-built and controlled systems can be considered suitable for production, the reliability and durability of the system and its components over extended mileage must be demonstrated. The performance of the catalyst is especially important. Since accumulation of 50,000 miles on a vehicle simulating typical customer use takes at least four months, and since few systems have yet reached the low-mileage emission targets, such durability data are sparse. Though more durability data are available on some of the system components, these must be used with caution since the laboratory conditions under which durability was tested are far different from the conditions that will be experienced with the complete 1975 system. This is especially true of catalyst tests performed with 1970 or 1971 production automobiles. Engines in these production vehicles operate with a leaner carburetor setting than is expected in 1975 model year vehicles, and hence with a lower HC and CO loading on the catalytic converter.

Deterioration in catalyst effectiveness is the greatest problem with all these systems. It causes vehicle emissions to rise steadily with accumulated mileage. This deterioration results in part from poisoning of the active catalyst material, and in part from damage to the catalyst surface structure caused by overheating. Both these effects

reduce the activity of the catalyst when fully warmed up; they also raise the bed temperature required for the catalyst to become fully effective. Emission control in both the cold-start and warm-engine phases is impaired.

It is well known that the lead compounds resulting from combustion of antiknock additives in commercial gasoline (present in amounts up to 3 grams lead alkyls per gallon) rapidly poison the active catalyst materials being used. Vehicles with catalytic converters must therefore be operated with "lead-free" fuel. However, today's "lead-free" gasoline still contains trace quantities of lead as well as other elements such as phosphorus and sulphur. All have been found to increase catalyst deterioration significantly. The concentrations of these elements in currently available "lead-free" gasoline are high enough to be of concern. Also lubricants, and detergent and dispersant additives, may contain small amounts of these and other elements that contaminate the catalyst material.

There is therefore a need for federal action to ensure wide availability of lead-free fuel at the time vehicles with catalytic converters come onto the road. Action is also required to control the amounts of catalyst poisons in the fuel. Some manufacturers' data suggest that fuel with less than about 0.03 gram lead alkyls per gallon, and less than about 0.01 percent sulphur and 0.005 percent phosphorus, may be required. It is also essential that the automotive and petroleum industries devise techniques for ensuring that vehicles that must use lead-free gasoline cannot have their fuel tanks filled with conventional leaded gasoline.

Catalyst damage due to overheating in vehicle use is not adequately understood. Certain vehicle-operating modes result in high exhaust-gas temperatures and high HC and CO concentrations. When these emissions are burnt up in the catalytic converter, the heat released in the oxidation process can raise bed temperatures to 1600°F or more and cause physical damage to the catalyst surface structure. Examples of detrimental vehicle-operation modes are sustained operation at high engine power and descent down long hills. The driving schedule used to accumulate mileage rapidly during driveability tests, while typical of average customer use, does not include several of these operating modes in which overheating can occur. Also, any engine failures, such as spark-plug misfire, which substantially increase HC and CO emissions, are likely to result in severe overheating and catalyst damage. While recent developments in catalyst technology have improved the structural properties of catalysts at high temperatures, there will probably still be a need for a catalytic converter by-pass system to prevent permanent damage to the catalyst in those modes in which overheating is likely. The by-pass system must seal tightly during normal use to prevent excessive emissions. It would be operated by signals from sensors measuring catalyst-bed or exhaust-gas temperature. Such systems are under development, but satisfactory performance has not yet been obtained.

Most of the oxidation catalysts tested on vehicles show an initial loss of activity, especially in CO-conversion efficiency, over the first few thousand miles of vehicle operation followed by a more gradual loss in activity over the subsequent tens of thousands of miles.

Data in Appendix G illustrate these points. Variations in emissions during engine startup at the beginning of the test and changes in carburetor settings as well as catalyst deterioration affect the emission results.

Few of the catalysts with the high initial activity required to achieve emissions close to the 1975 standards have yet been tested over extended mileage. Not all the tests made were conducted with HC and CO loadings on the converter comparable to those expected with the complete 1975 system. For example, exhaust-gas recirculation to control NO_x emissions was not always used. Since this requires enrichment of the fuel-air mixture to maintain adequate vehicle driveability, HC and CO emissions from the engine itself increase. Increasing the load on the converter appears to result in faster catalyst deterioration.

Only a few of the automobile manufacturers have carried out durability tests with their 1975 emission-control systems over sufficient mileage to allow estimates of deterioration over 50,000 miles. The best results available to date with catalytic converters in emission-control systems similar to those being developed for 1975 model year vehicles are summarized in Table 3.3. The emissions measured at low mileages were not always below the 1975 HC and CO standards. The 50,000-mile deterioration factor is the ratio of emissions measured at 50,000 miles to emissions measured at 4,000 miles. Smoothing of the data is required to obtain this factor because the scatter can be up to $\pm$ 50 percent about the average, due to variation in control-system performance and test procedure. The best measured or projected increase in emissions over 50,000 miles is by a factor of 2.5 or more when low-mileage emissions were below the 1975 HC or CO standard. While lower deterioration factors have been measured when initial emissions levels were above the 1975 HC or CO standards, it is not clear that this improved performance can be retained as the activity of the catalyst is increased to reduce emission levels below the standards. At this time, automobile manufacturers do not have adequate data to assess the durability of their catalytic converters over extended mileage. Their experimental vehicles with promising low-mileage emissions have exceeded one or both of the 1975 HC and CO standards early in the durability tests. Catalyst replacement during the 50,000-mile durability test would improve this situation. Whether emissions after catalyst replacement would be close to the values achieved at low mileage would depend on the deterioration of engine adjustments and other components in the system that affect emission control.

Table 3.3

Deterioration in Emission Control Over 50,000 miles[a]

Catalyst Type		Emission (g/mile) at 4,000 miles	50,000-Mile deterioration factor[b]
A-Base metal, pellets	HC	0.6	2.8
	CO	10	2.4
B-Base metal, pellets	HC	0.24[c]	2.5
	CO	5.4 [c]	1.6
C-Platinum, monolith[d]	HC	0.19	2.5
	CO	4.2	2.5
D-Base metal, pellet	HC	0.8	1.5
	CO	9.5[e]	---

[a]Examples of best results obtained to date over 50,000-mile durability tests by automobile manufacturers with control systems similar to those being developed for 1975 vehicles. CVS-C test procedure used (see Table 3.1) except where noted. Data supplied to Panel on Emission Control Systems.

[b]Deterioration factor as used by EPA is emissions at 50,000 miles divided by emissions at 4,000 miles. A straight line is drawn through the emissions data plotted against mileage to obtain this ratio. The scatter in the data about this line is about $\pm$ 50 percent.

[c]These emissions measured with 1975 test procedure at zero miles.

[d]No EGR used with this vehicle. When EGR is used to reduce NO_x emissions below 3 g/mile, HC and CO emissions from engine will rise.

[e]Average value. CO emissions varied over the range 6.5-14 g/mile. Not possible to determine a deterioration factor.

The durability of other components in the emission-control system has not yet been adequately demonstrated. EGR systems show deterioration with mileage due to plugging of the recycle line and control valve with deposits. While the manifold reactors used by some manufacturers have shown promise of extended mileage durability under normal operating conditions, their ability to withstand higher temperatures during extreme operating conditions is open to question. Quick heat intake manifolds are a new development and their durability has not been adequately assessed.

It is also essential that new production carburetor and choke designs, and quick heat manifolds, be thoroughly proven in field-testing before they are placed on customer cars. Proper fuel-air mixture preparation is a critical element in assuring adequate and safe vehicle operation and the effectiveness of the emission-control system.

In view of these problems it should be asked whether systems with a catalytic converter as the major HC and CO burn-up device are the best choice. The alternative is a system with a manifold thermal reactor. The best low-mileage emissions results reported to date with two different thermal-reactor concepts are given in Table 3.4. The best results obtained with a proposed 1975 catalytic converter system are included for comparison. The thermal-reactor system includes EGR and fuel-rich carburetion to control NO_x. It also requires this rich carburetion to provide enough chemical energy in the engine exhaust to hold the reactor core at high enough temperatures for burn-up to be effective.

The main problems with the thermal-reactor system are: substantial fuel-economy penalty (e.g., 17-22 percent for reactor B); inadequate CO-emission control; inability to control NO_x emissions to the 1976 standard (the thermal reactor bolts directly onto the cylinder head and does not provide the proper reducing atmosphere for an NO_x catalyst); need for over-temperature protection, and high emissions in the event of failure. At present, the Committee judges that the oxidizing-catalytic-converter approach offers more promise of meeting the 1975 standards and better potential, with a reducing catalyst, of meeting 1976 NO_x levels (the oxidation catalyst can be located downstream of the NO_x catalyst).

3.4 System Compatibility with 1976 NO_x Standard

An important consideration is the potential of the 1975 control systems, with further development, to meet the 1976 NO_x-emission standard of 0.4 g/mile. Almost all manufacturers have focused their development efforts on control systems that can achieve much lower NO_x emissions than are required in 1975.

NO_x control to below 3 g/mile in the systems proposed for 1975 model year vehicles is achieved with EGR, fuel-air mixture enrichment, and adjustments in spark timing. The best NO_x control achieved in

Table 3.4

Best Low-Mileage Emissions from Thermal-Reactor Systems*

	Emissions, grams/mile		
	HC	CO	NO_x
Thermal-Reactor Concept A	0.05	9.2	0.51
Thermal-Reactor Concept B	0.1	4.0	0.7
Best 1975 Catalytic-Converter System	0.13	1.9	1.3

* As of November 1, 1971

experimental vehicles by using increased amounts of EGR and richer mixtures is 0.8 - 1.0 g/mile. A fuel-economy penalty of 20 percent or more results, and the HC and CO loading on the catalyst is increased. Attempts at greater NO_x control with these approaches lead to higher HC and CO emissions, an increased fuel-economy penalty, and poor vehicle driveability. The 1975 proposed California NO_x standard of 1.5 g/mile may even be beyond the capabilities of some of the systems being developed to meet the federal 1975 HC and CO standards (see Table 3.2).

While EGR with fuel-air mixture enrichment is effective in reducing NO_x emissions to levels approaching 1.5 g/mile, it is not a satisfactory method of achieving the very low NO_x emissions required in 1976. Large amounts of EGR (about 20 percent) degrade engine performance and fuel economy and significantly increase the difficulty of HC- and CO-emission control. The use of rich mixtures results in high engine HC and CO emissions. The increased thermal load on the catalytic converter makes damage from overheating more likely; in the event of catalyst failure, the vehicle emissions would be greater than those from current new vehicles.

The basic 1975 emission-control systems now being developed will require either the addition of a high-performance NO_x-reducing catalyst in addition to an oxidation catalyst, or an effective three-way catalyst (which controls NO_x, HC, and CO emissions) to achieve NO_x control to the level of the 1976 standards. In the first approach, the additional NO_x catalyst bed would be placed in the exhaust system upstream of the HC- and CO-oxidizing catalyst. Recalibration of the carburetor to a richer setting to provide a reducing exhaust-gas stream would be required. Some EGR would probably be retained to reduce the NO_x levels entering the NO_x catalyst bed. The secondary air would be added downstream of the NO_x catalyst once the system was warmed up. During the warm-up phase, secondary air would be added in the exhaust manifold and the NO_x catalyst would act as an oxidizing catalyst to control HC and CO emissions. If a three-way catalyst were to prove practicable, all three pollutants could be controlled in one converter and a simpler system would result. For both these approaches, the carburetor setting used for the 1975 systems would need recalibration. The measures taken to control emissions in the 1975 system while the engine warms up may not be as effective in these 1976 systems and additional development of the system to adequately control HC and CO emissions during the engine and catalyst bed warm-up phases would then be required.

Laboratory-engineered systems of this type are now being evaluated, but the technology of suitable NO_x-reducing catalysts or three-way catalysts is not nearly as advanced as the technology of oxidation catalysts. Although NO_x-emissions reductions to levels approaching the 1976 standard of 0.4 g/mile have been achieved on a few experimental vehicles, the catalyst durability is poor, and the mass-production potential of these

systems cannot yet be established. Contacts between the Committee and catalyst manufacturers have indicated optimism among the catalyst manufacturers that a three-way catalyst system can be developed. Efforts in this area during the next year will be monitored very closely by the Committee.

The techniques proposed to control NO_x emissions make it harder to achieve HC- and CO-emission control to the levels required by the 1975 standards. The use of EGR as explained above requires mixture enrichment to maintain vehicle driveability and increases the engine's HC and CO emissions. The inclusion of an NO_x-reduction catalyst adds extra mass upstream of the oxidation catalyst and, therefore, slows down the warm-up of this HC and CO converter during the cold-start portion of the test. The use of an NO_x catalyst also requires some mixture enrichment to provide the correct composition of gases entering the catalyst chamber.

3.5 Effects of Emission-Control System on Vehicle Performance

Three areas of vehicle performance are likely to be adversely affected by the 1975 emission-control systems. These are fuel economy, vehicle-acceleration capability, and vehicle driveability (or ability to perform adequately in all normal operating modes and ambient conditions).

Reductions in compression ratios for 1971 and later model year vehicles, to enable these engines to burn 91-octane gasoline, have already resulted in losses in fuel economy and acceleration capability for engines of given displacements. The use of EGR to control NO_x emissions is the primary cause of the expected additional performance losses in 1975 model year vehicles. Because EGR slows down the combustion process inside the engine, the fuel-air mixture must be enriched to maintain flame speeds and retain adequate driveability. Spark retard is also used and has a similar effect. Data from the automobile manufacturers indicates that these changes are expected to result in a direct fuel-economy penalty of 3 to 12 percent compared with 1973 prototype vehicles, depending on engine size, axle ratio, vehicle weight, and details of the emission-control system.

Again because EGR is used, the power output for a given engine displacement, engine speed, and throttle setting is reduced. Because the fresh mixture is now diluted, less fuel and air enter the cylinder, and the effective size of the engine is decreased. The resulting loss in acceleration capability can be offset by increasing engine displacement (which results in a further fuel-economy penalty) and by cutting out EGR at wide-open throttle. The precise performance loss is difficult to estimate at this stage, since it also depends on details of engine size, vehicle weight, and the emission-control system. It is likely that some of the smaller engines now available in some model lines will have to be discontinued, due to the reduction in performance of such engines to unacceptable levels when operated with EGR.

The effects of emission controls on vehicle driveability are difficult to quantify. Driveability after a cold-engine start, and especially with cold ambient conditions, is likely to be impaired. To reduce HC and CO emissions during engine warm-up, the choke is set to release quickly, and the fuel-air mixture is leaned out as early as possible after engine startup. Under these conditions, problems of engine stall, and vehicle stumble and hesitation on rapid acceleration, have been prevalent. Vehicle stall and stumble are safety hazards in some traffic situations. Similar problems during startup and drive-away after a hot-engine restart have been experienced. By careful tailoring of the fuel-air mixture control, such problems have in the past generally been resolved, though there has been a deterioration in driveability in 1971 and 1972 model year vehicles. The impact of more stringent air-fuel ratio control for 1975 model year vehicles on vehicle driveability cannot yet be accurately established, because these 1975 prototype systems have not been tested under a wide range of ambient conditions. The use of EGR affects driveability. Adequate vehicle performance depends on good mixture preparation and distribution between the different engine cylinders to avoid engine misfire. Exhaust gas is one more component to be mixed with the fresh mixture in the intake manifold. It makes this problem more critical because it reduces the tolerable cylinder-to-cylinder fuel-air variation.

The successful resolution of many of these driveability problems depends on extensive field-testing of production prototypes. The vehicles need to be tested under as complete a range of vehicle-operating modes and ambient conditions as possible. This is an essential stage in the development process if the engine and emission-control system are to perform safely and reliably in the customer's hands. Severe driveability problems could have significant safety implications.

3.6 Developments Required to Meet 1975 Standards

From the data reviewed in Section 3.3, it is clear that no major manufacturer has yet demonstrated the technology needed to meet the requirements of the 1970 Clean Air Act Amendments of 1975 model year vehicles. However, both the automobile and catalyst manufacturers have intensive development efforts under way. Thus, there remains some possibility that a control system can be developed in time to permit the mass production of vehicles that will meet the 1975 standards.

It must be stressed that the major automobile manufacturers are at different stages in this development. Also, although the control systems being proposed for 1975 by most manufacturers are similar in concept, the details of the system components differ significantly among them and the integrated systems have been optimized for different engine-operating conditions. Fuel-air ratios used and mixture preparation are two important differences. Thus, although one or perhaps two manufacturers

have shown on a few of their vehicles that their systems have the potential of meeting the low-mileage emission targets, it is not clear that the other manufacturers' systems, in their present forms, have this potential. Especially important are the variations in catalyst durability obtained by different automobile manufacturers using catalysts that, according to laboratory tests, should have similar properties. The different HC and CO loadings on these catalytic converters appear to be significant.

Most manufacturers evaluate the low-mileage emissions performance of their systems in relation to emission targets, which, as shown in Table 3.2, are substantially below the 1975 standards. Intensive durability testing commences only when the system shows promise of reaching these targets. It must, therefore, be asked whether these targets are realistic or unduly stringent. This depends in part on decisions the Administrator of EPA has yet to make. One decision is whether only the average emissions of production-line vehicles, or all or almost all vehicle emissions, must be below the standard (Section 2). The second is what maintenance procedures are allowed during the 50,000-mile certification test. The question of catalyst replacement at more frequent intervals than 50,000 miles is crucial. The targets listed in Table 3.2 assume that only the average of production-line vehicle emissions must be below the standards for the vehicle's useful life, that provision is made for catalyst replacement and other maintenance during the certification procedure, and that fuels with sufficiently low levels of catalyst poisons will be widely available. Available catalyst durability data and a reasonable assessment of improvements likely over the next year or so suggest that, without catalyst replacement, these low-mileage targets are optimistic. If catalyst replacement at 20,000 - 30,000 mile intervals is to be allowed, and if these anticipated improvements in catalyst performance are realized, then these targets represent a reasonable judgment of necessary low-mileage performance of the emission-control system.

The developments required to enable most major manufacturers to meet the 1975 standards in 1975 model year vehicles can now be laid out. First, an experimental version of the control system must be shown capable of meeting the necessary low-mileage emission targets. One or two manufacturers have reached this stage with HC emissions and are approaching this stage with CO emissions provided the assumptions about averaging, catalyst replacement and maintenance already described can be applied. Second, the durability not only of the catalyst but of the entire experimental systems must then be demonstrated under conditions typical of both normal and extreme customer usage. Better built-in control of engine adjustments than in present engines will be essential. Catalysts with initial activity equal to that of the best materials now available, but with improved durability, will be required. It appears now that catalyst replacement within 50,000 miles will be necessary to prevent deterioration in HC- and CO-emission control by more than a factor of 2 and, hence, to retain low-mileage emission targets at 50 to 60 percent below the standards.

For those manufacturers who are close to meeting their low-mileage goals and who have already demonstrated catalyst durability approaching what will eventually be required, these developments are extrapolations of their current technology. The development effort required to realize these improvements in time for 1975 model year production may be such that only the larger manufacturers have sufficient resources.

A critical factor in this development process is the need for extended reliability and durability testing, not only of the engine and emission-control system, but also of other vehicle components whose design must be changed as a result of emission control. Examples of such changes are redesign of parts of the vehicle frame to obtain extra space for enlarged exhaust manifolds and catalytic converters, and modifications to power steering and brakes as EGR changes the intake-manifold vacuum. Most of these additional problems can be solved with standard engineering techniques; there will be many such changes, however, and each new component must be adequately tested before mass production.

Historically, the automobile manufacturers have introduced new components only after extensive testing on a small part of their total production. The reasons for this are sound; customers use their vehicles in a wide variety of ways and expect reliable, safe, and satisfactory performance. Adequate design data become available only after customer field experience has been obtained. This process can be accelerated by increasing development effort, but time contraints for 1975 model production are such that many engineering decisions may be made during the next two years without benefit of adequate information.

3.7 Stratified-Charge and Wankel Engines

Two alternative spark-ignition engine concepts have received considerable attention of late. These are the stratified-charge and the Wankel rotary-combustion engines. Neither of these concepts is new. The stratified-charge principle was first suggested in the early 1920's; the Wankel engine in its current form dates back to 1957. Emission control is one of the several reasons for the renewed interest in these alternative approaches. These engines would represent a less radical change than other low-emission alternatives such as gas turbines and Rankine cycle engines. Their low-emission potential relative to conventional spark-ignition engines, and the time scale required to realize that potential, are important considerations.

Several different stratified-charge engine concepts are now being explored at the research stage. In each of these, fuel is injected directly into the engine cylinder. The engine geometry, timing of fuel injection, fuel and air-flow patterns, spark-plug position, and spark timing are all carefully adjusted so that combustion of the stratified fuel-air mixture inside the cylinder takes place under conditions that

minimize pollutant formation. With precise control of mixture preparation and combustion over the entire engine speed and load range, the basic engine emissions are considerably below those of conventional engines. The emissions are not at this stage low enough to meet the 1975 or 1976 standards without additional control devices such as EGR and a catalytic converter.

The two most advanced versions of the stratified-charge concept are being developed for the U. S. Army Tank-Automotive Command's M151 military jeep. The engine for this vehicle is a four-cylinder engine nominally rated at 70 horsepower. The version of this engine developed by the Ford Motor Company was tested recently by EPA and gave emissions at low-vehicle mileage below the 1975 and 1976 standards.

However, this engine is far from ready for mass production. It is known that tolerances on engine adjustments to maintain this low-emissions performance are narrow; no data are yet available on the durability of these adjustments over extended mileage. Components such as the fuel injector and spark plugs are laboratory prototypes, and designs suitable for mass production need to be developed. The low-emissions results were obtained in a low-powered military vehicle with driving characteristics different from those of a normal passenger car. The low-emissions potential of the system on larger engines in full-size vehicles is only now beginning to be explored.

Another type of stratified-charge engine is being developed with a divided chamber or prechamber design. Fuel-air stratification is obtained by injecting fuel into a precombustion chamber. The resulting fuel-air mixture is sparked, and burning gases then enter the main chamber above the piston where they mix with excess air and burn to completion. This concept is still in the research stage though it also appears to have inherent low-emissions characteristics.

The low emissions of these existing experimental stratified-charge engines may make this engine attractive in the longer term. This engine may also offer a fuel-economy advantage compared with emission controlled conventional engines. However, its potential for the mass automotive market cannot yet be accurately assessed. It represents a more radical departure from current technology than might appear at first sight. The cylinder head, piston, intake port and intake manifold geometries are all different from those of a conventional engine and designs have not yet been fully optimized. The fuel injector and nozzle must provide better spray control than is achieved in diesel engines. The spark plugs extend into the cylinder and require a different electrode configuration. All these changes present new design and durability problems. Several manufacturers now have development programs to explore the potential for the stratified-charge engine; only when results from these programs become available can sound judgments as to its future be made. Even with the most optimistic

development schedule practicable, 1978 is the earliest date at which this engine could be introduced into a substantial fraction of any manufacturer's product line

Wankel engine technology is further advanced. Though NSU's early experience with limited production of this engine in Germany was not encouraging, Toyo Kogyo in Japan have successfully marketed Wankel engines for the last three years. A major problem has been rotor apex seal wear, but acceptable solutions now appear to have been found. The claimed advantages of the engine are: lighter weight, smaller size, smoother and quieter operation, and fewer moving parts. It is therefore claimed that it would be cheaper to manufacturer.

The emission characteristics of the engine have not been explored as extensively as have those of the conventional engine. There are variations in geometry between different Wankel engine designs that appear to affect emissions significantly. In current production Wankel engines, HC emissions from the engine itself appear higher, CO emissions are about the same, and NO_x emissions are lower than emissions from a comparable reciprocating engine. The lower NO_x emissions appear to be a significant advantage. Much of the emission-control technology being developed for conventional engines can be applied to the Wankel engine. However, the optimization of the engine design for low emissions and integration with other control devices, such as thermal reactors and catalytic converters, is at an earlier stage of development.

The claimed advantages of the Wankel engine lie primarily in areas other than emissions. Thus, while a small fraction of 1975 model year vehicles may use Wankel engines, the HC- and CO-emission-control problem will not be substantially different.

4. MAINTENANCE

The emission-control systems necessary to meet the 1975 and 1976 model year standards are complex systems that must be carefully controlled and maintained to enable a vehicle to continue to meet the standards for 50,000 miles, and have very low emissions for their entire life. For example, more precise fuel metering will be required. Control of the air-fuel ratio will have to be maintained to within narrower limits than heretofore has been required or possible. To try to obviate the difficulties of ensuring adequate and proper maintenance, there will have to be an increased tendency to replace rather than repair or readjust defective parts, e.g., sealed, electronic ignition systems. This will involve, in many cases, an increase of maintenance costs.

A critical item in the 1975 emission-control system is the catalyst. As discussed previously, whereas some manufacturers have attained results below the 1975 emission standards on experimental vehicles, no one has yet been able to do this for 50,000 miles, catalyst durability being a critical problem. According to the federally prescribed emission-test procedure relating to durability, a major engine tuneup is allowed at 24,000 miles with replacement of spark plugs, condenser, breaker points, etc. The lack of a catalyst of proven durability may require that replacement of the catalyst at specified intervals be permitted in the federal emission-test procedure and also become part of the standard maintenance procedure indicated in manufacturers' warranties.

The problem of maintenance of emission-control systems is made more difficult by the fact that devices such as manifold thermal reactors and catalysts may fail without the motorist even becoming aware of it. As discussed previously, the inadvertent use of leaded gasoline or the failure to replace a misfiring spark plug may well cause irreversible damage to the catalyst. Under these conditions it is possible for the vehicle actually to emit as much or even more pollutant material than the vehicle without a catalyst and EGR, because of the richer carburetor setting required by the emission-control system.

Further, the motorist will have no natural incentive to have maintenance performed on his vehicle. The EGR system, for example, carries a loss of performance and increases fuel consumption. There is an apparent advantage to the individual motorist in allowing this system to plug up, or even purposely to disable it.

The additional maintenance cost of a 1975 or 1976 model year car is difficult to estimate, since even experimental vehicles have not exhibited satisfactory 50,000-mile durability. Accurate cost estimates cannot be made until such vehicles have been in service in the hands of customers. Many motorists will not voluntarily pay the necessary costs to maintain their cars at low emission levels,

with poorer performance and impaired driveability as the penalty. If the additional emission control is to be realized in service, it is necessary that adequate maintenance be required for the life of the vehicle. Procedures to ensure such maintenance might include state or local laws prohibiting deactivation of emission-control systems and requiring that they be maintained, state or local inspection requiring correction of cars with excessive emissions, and required replacement of certain components at specified intervals. Since some of the emission-control systems are not yet completely developed, failure modes are not well enough known to determine the best method of enforcement at this time. The problems of developing enforceable procedures, including the provision of economically feasible test equipment and personnel training, have not as yet been attacked by either the automotive industry or public bodies.

5. MANUFACTURING

In order to prepare for production of 1975 model year vehicles, new production facilities will have to be made available for such items as air pumps, catalytic-converter housings, catalysts and their carriers, and a multiplicity of valves, regulators, and safety devices. New or extensively modified production facilities will have to be provided for new carburetion and ignition systems, new exhaust and intake manifolds, and new engine heads. Final assembly-line and subassembly-line additions and modifications will be necessary. The task of providing facilities for meeting the 1975 values is a large one.

Long lead times are required to design, erect, and equip modern mass-production facilities. The design of some manufacturing equipment has already been detailed and irreversible decisions will have to be made by mid-1972 if the industry is to be ready for August 1974, full-scale production. A typical example of the time schedule for critical equipment construction is shown in Table 5.1. Compared with normal practice in the automobile industry this is an accelerated schedule. The most undesirable features of the schedule are the inadequate time allowed for gaining sufficient experience with production vehicles in customers' hands and the very limited time available to correct and adjust production equipment, processes and procedures.

Some of the tooling will be more sophisticated than has been previously made for the automobile industry. For instance, carburetors will have to be inspected and adjusted by advanced modern electronic techniques before installation. In turn, machined parts will have to be made on machines capable of correcting any dimensional errors that might develop.

Most automobile companies purchase many component parts from vendors. The rapidly fluctuating thinking about design criteria for items such as catalytic converters so retards decision-making that vendors cannot commence the construction of production facilities and assume amortization of their own investment until firm commitments are made.

It has become apparent that if engines are designed and manufactured to close dimensional tolerances, the emission characteristics of the vehicles will be much more consistent. It will be costly and require much change in management techniques for the automobile industry to acquire expertise and equipment for adequate quality control. It will also be difficult to arrange for similar control of vendors' products, although the techniques of quality control are well known in other industries and can be acquired.

Table 5.1

Scheduling and Lead Times for Mass Production

January 1, 1971	-	Accelerate design of heavy machine tools. Make preliminary designs of emission-control systems. Accelerate emission testing on vehicles. Make preliminary designs for most tooling.
July 1, 1971	-	Approve design for large machines and make layouts for new factories and major modifications. Select tentative design for emission-control system.
January 1, 1972	-	Prepare materials for requesting bids. Start final phase of obtaining facilities approvals.
April 1, 1972	-	Finalize design of emission-control system for production.
July 1, 1972	-	Make contracts for vendor-manufactured items. Make contracts for equipment. Make contracts for production tooling. Start accelerated testing program of handmade vehicles.
January 1, 1973	-	Order materials. Finish design of minor tooling and factory rearrangements. Redesign to meet change requirements.
July 1, 1973	-	Start production tests from partial tooling. Start certification runs. Accelerate production plans. Start extensive field tests of vehicles.
January 1, 1974	-	Complete component-production facilities and start production. Start intensive preparation of equipment for making pilot production on mass-production equipment.
July 1, 1974	-	Start production of automobiles. For the entire industry, this is at a rate of approximately 10 million vehicles per year.
January 1, 1975	-	Evaluate field behavior of mass-produced vehicles and introduce minor modifications.

The emission values are critically associated with configuration and dimension control. The closer the dimensions approach the values specified for a particular configuration, the closer the emission values will be to those required by the Act.

The Committee was sympathetic to all these difficulties. Nevertheless, based on information provided by a Committee Panel and based on the evaluation of the Committee, it is the opinion of the Committee that the automobile manufacturers have the experience and capability to arrange to mass produce the type of hardware indicated in Section 3 that would be necessary to meet the 1975 standards in sufficient time. However, as was discussed in Section 3, data presented to the Committee (Appendixes F and G) show that, at present, not even experimental vehicles are available that can satisfy the complete requirements of the 1975 standards. Thus, even though the hardware for the 1975 model year vehicle can be outlined, improvement and optimization of the emission-control systems will be necessary in order to provide the necessary reliability and durability to achieve the 1975 requirements in service.

Likewise, as a result of panel visits to catalyst manufacturers, the Committee has been informed that, within one year after receipt of a firm purchase order, the catalyst manufacturers could install sufficient capacity to supply the projected needs of the automobile manufacturers, once an acceptable catalyst is developed or identified. The Committee emphasizes that according to the data provided to it by both the automobile manufacturers and the catalyst suppliers, as shown in Appendix G, there has, as yet, been no demonstration of an adequate oxidation catalyst of sufficient durability to satisfy the 1975 requirements.

6. COSTS OF MEETING 1975 EMISSION REQUIREMENTS

The designs for the emission-control systems for vehicles to meet the 1975 requirements are now definite enough so that the initial cost to the customer can be estimated. Estimates of the range of additional initial costs to the ultimate customer for meeting the 1975 requirements over the 1970 requirements were requested of foreign and domestic automobile manufacturers in Question 17 of the questionnaire. Replies were based on the assumption that only the average emissions of vehicles need meet the standards, and that a 100-percent assembly-line test will not be required; 50,000-mile warranty costs are not included. Several of the foreign manufacturers indicated that the state of development of their 1975 emission-control systems was such that they could not now give a realistic estimate of additional costs. Of the seven foreign manufacturers that did reply positively to the question, estimates ranged from $200 to $500.

Of the five American manufacturers, two submitted estimates of about $250 while the others were of the order of $500. The higher estimates reflected the proposed use of a thermal reactor as well as a catalyst in the emission-control system.

To provide substantiation of the manufacturing estimates, the Panel on Manufacturing and Producibility has made an independent study of these costs. The system used for the Panel estimates was one that in light of the results of Section 3 of the report, appeared most promising. The cost effectiveness of the thermal reactor and associated hardware was so poor that this item was not included in the system.

Table 6.1 shows, on a year-by-year basis, the items that have been added to current vehicles for emission-control and also those that will be added for a promising system for 1973, 1974, and 1975 model year vehicles. In estimating the cost of these items, the Panel assumed that all vehicles in the certification fleet will perform within the 1975 standards for 50,000 miles with no more than one catalyst change allowable, that automobile manufacturers will substantially increase their in-house testing and quality control of major components so that no additional end-of-the-line rework will be necessary, that a short end-of-the-line test will be used to identify grossly malfunctioning vehicles with the full CVS-CH test done only on a small statistical sample by engine family, and that only the average emissions of customer vehicles must satisfy the federal standards.

For the Panel estimates, the cost of a component was based on such factors as the typical cost per pound of worked or machined metal and the actual price charged by parts dealers in California for similar components already used in California cars. Tooling and equipment were amortized over three years, dealer margin was taken as 22 percent of the

Table 6.1

Typical Pattern of Installation of
Automotive Emission Hardware

Model Year Added	Item
1966	PCV valve
1968	fuel-evaporation-control system
1970	a) retarded ignition timing b) decreased compression ratio c) change of fuel/air ratio d) transmission control system
1972	a) anti-dieseling solenoid valve b) thermostatic air valve c) choke-heat by-pass
1973*	a) exhaust-gas recirculation b) air-injection reactor c) induction hardened valve seats d) spark-advance control e) air pump
1974*	precision cams, bores, and pistons
1975*	a) proportional exhaust-gas recirculation b) carburetor with altitude compensation c) advanced air-injection control d) air/fuel preheater e) electric choke f) electronic distributor (pointless) g) improved timing control ($\pm$ 1) h) catalytic (oxidizing) converter i) catalyst pellet charge j) cooling-system changes k) improved underhood materials l) body revisions

*Hardware listed for 1973, 1974, and 1975 model years is for a system deemed by the Panel to be promising.

sticker price, profit as 10 percent of the list price, and excise tax 5 percent of the sticker price. Excise tax was included in both the Panel and the manufacturers' estimates. Details of the Panel's estimates are given in Appendix H and results shown in Table 6.2. The Panel estimate shows an increase of initial cost of $288 for the 1975 model year projected system over the 1970 model year system, and an increase of $214 for the 1975 system over the 1973 system.

The increased dollar cost of a vehicle to the customer at the time of purchase is only part of the true cost to the user. According to the manufacturers' estimates the reduction in fuel economy to achieve the 1975 values will increase fuel consumption by 3 to 12 percent. The Committee anticipates that the cost of routine maintenance may increase by several times present costs depending on inspection procedures that are prescribed and enforced. There will be some deterioration in vehicle driveability.

Whether these costs are justified by the benefits to be gained is outside the scope of this interim report. But it should be noted that many who have concerned themselves with restoration of the quality of the environment have indicated that this process must necessarily be expensive and would probably include the necessity to forego certain material advantages made possible by a less regulated industrial technology. The present instance would appear to be a significant case in point.

Table 6.2

Summary of Cost for Likely Emission Hardware
Based on Panel Estimates

Year	Yearly Cost	Accumulated Cost
1966	$ 3.00	$ 3.00
1968	15.00	18.00
1970	8.00	26.00
1971-1972	14.00	40.00
1973	60.00	100.00
1974	20.60	120.60
1975	193.40	314.00

7. THE CONSEQUENCES OF A ONE-YEAR SUSPENSION OF 1975 STANDARDS

The current state of the art of emission-control technology, as presented in this report, strongly suggests the likelihood that some, if not all, of the automobile manufacturers will request that the Administrator grant a one-year suspension of the emission standards applicable to 1975 model year light-duty vehicles. At this point, it is useful to discuss the possible consequences of the granting of such a suspension.

At present, not even experimental vehicles have been shown to satisfy the 1975 emission standards for 50,000 miles. Certainly, developmental work is still required to further reduce emissions at low mileage and to provide the required durability. Durability testing is expensive and time-consuming; three to four months are required for a 50,000-mile test. Each major change in the basic system configuration or operating conditions will require new durability tests on components such as the catalytic converter. Catalyst technology for automotive emission control is relatively new, and some of the failure modes now being experienced are not well understood.

One important advantage of a one-year suspension, therefore, is that it would allow an additional year's work on development of the complete emission-control system before major design details of components must be "frozen" for production. Systems may need significant modifications before they can achieve both emission levels close to their low-mileage targets and improved catalyst life. The basic system configuration must shortly be fixed if the engine and control system are to be in mass production in 1974. Most manufacturers do not at this stage have adequate information to make many of the major engineering decisions that would be required over the next six months.

Furthermore, uncertainties in the definition of compliance need to be resolved by EPA before major commitments to production of the control systems are made. If decisions made on the concept of averaging emissions and on allowable maintenance during certification increase the difficulties of meeting the requirements of the Act, then further improvements in emission reduction beyond the best results achieved to date will be required.

As has been explained, many engine modifications are required in these prototype 1975 vehicles. With such a large number of modificat there is considerable question of the overall system reliability in t hands of customers. Approximately 10,000,000 new vehicles will be purchased in 1975 by customers with a wide variety of driving habits. Conditions to which an emission-control system would be exposed by the driving public are more variable and extreme than those to which it would be exposed during the emission test. Extensive road testing under the ambient conditions experienced throughout the United States is essential to give the

manufacturer an understanding of problems and failure modes that will occur in practice. For the 1975 model year, the time scale is so short that many new production items will not be adequately proven. An example of such a critical item is the new carburetor design many manufacturers intend to use. Normal field testing and durability testing of production samples of such components may not be completed before these components are installed on assembly-line vehicles. Problems may therefore occur in customer use that did not show up in the limited test period now available. The public may be buying vehicles whose components are more likely to malfunction and whose driveability and reliability may not be satisfactory. A year's suspension would give more nearly adequate time for component durability and system reliability testing and thus would give the customer added assurance that the additional expenditure in emission control is indeed effective in improving air quality.

An essential requirement for effective emission control over extended mileage for vehicles with catalytic converters is wide availability of fuel of sufficiently low lead, sulphur, and phosphorus content. Not only must there be sufficient production of such fuel; there must also be available pumps, storage tanks, and transfer equipment that are free of contaminants. A year's delay in the imposition of the standards would help to ensure the nationwide availability of such fuel and facilities.

The necessity for adequate maintenance of emission-control systems has been discussed. Enforced inspection and maintenance procedures will be required to assure that the owner will pay the cost involved in adequately maintaining his vehicle's emission-control system. An extra year would again help the development of inspection programs and ensure the availability of inspection facilities in areas in which they will be required.

One of the more important factors that needs to be considered in the decision of whether or not to grant a suspension is the effect on total automobile emissions and overall air quality. A simple way to estimate the effect of the suspension is to calculate the change in total emissions from all automobiles in the late 1970's and 1980's if meeting the 1975 standards is delayed for one year. The ratio of total emissions at some future date to emissions now will be a measure of the improvement in air quality likely to be achieved. Figures 7.1 and 7.2 have been prepared for the purpose of evaluating these effects, and show the results of a one-year delay in implementing the 1975 emission standards for hydrocarbons and carbon monoxide. These curves take into account such factors as the vehicle-age distribution among all automobiles, the decrease in vehicle miles driven per year per car as vehicle age increases, the predicted nationwide growth in vehicle miles driven each year, the emission reduction achieved through crankcase blowby and evaporative-loss control, the effect of federal exhaust emission standards, and deterioration with mileage of emission controls from 1968 to 1974 model year cars. This deterioration

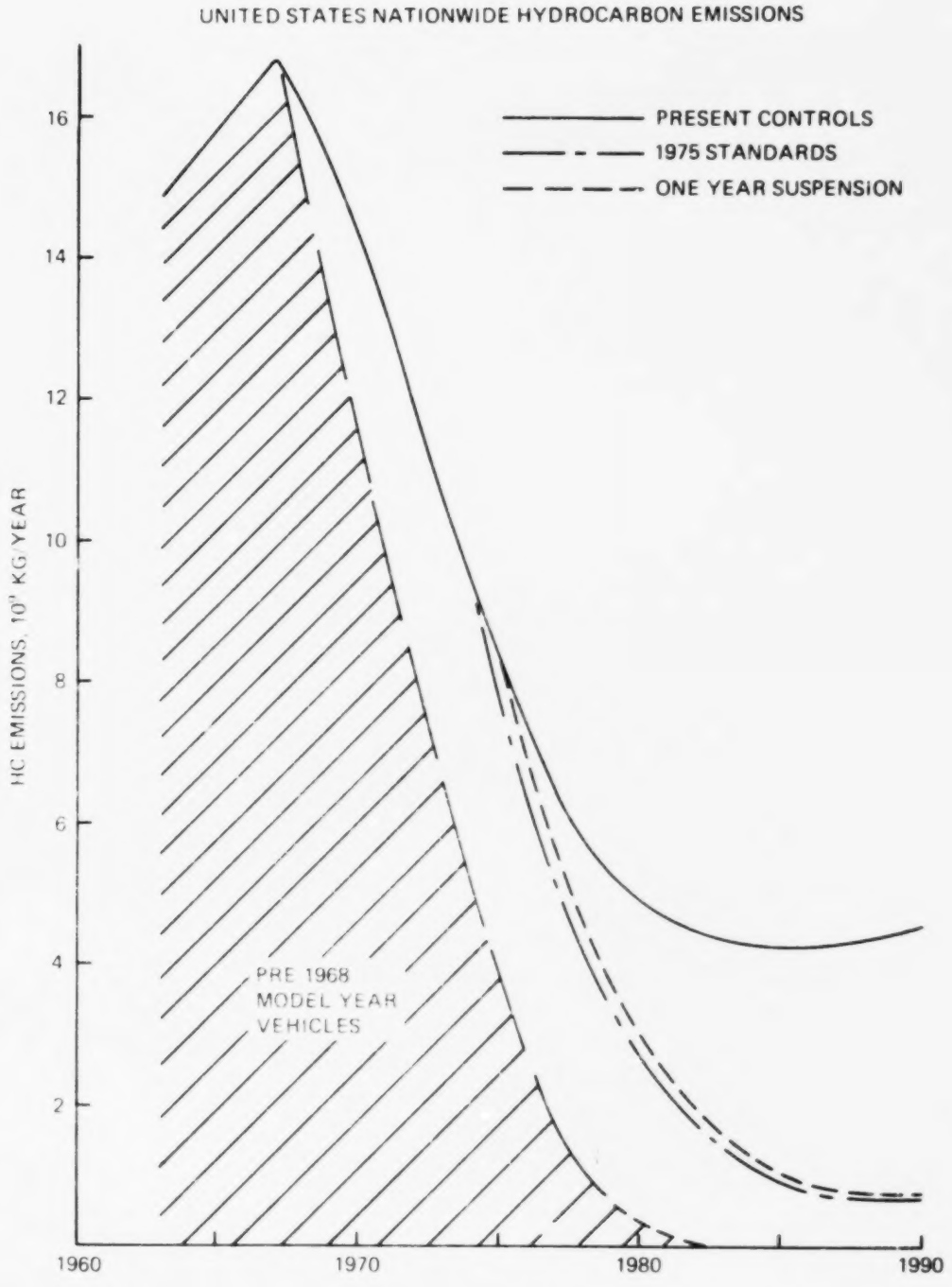

UNITED STATES NATIONWIDE HYDROCARBON EMISSIONS
PRESENT CONTROLS
1975 STANDARDS
ONE YEAR SUSPENSION
HC EMISSIONS, 10⁹ KG/YEAR
16
14
12
10
8
6
4
2
PRE 1968
MODEL YEAR
VEHICLES
1960
1970
1980
1990

Figure 7.1

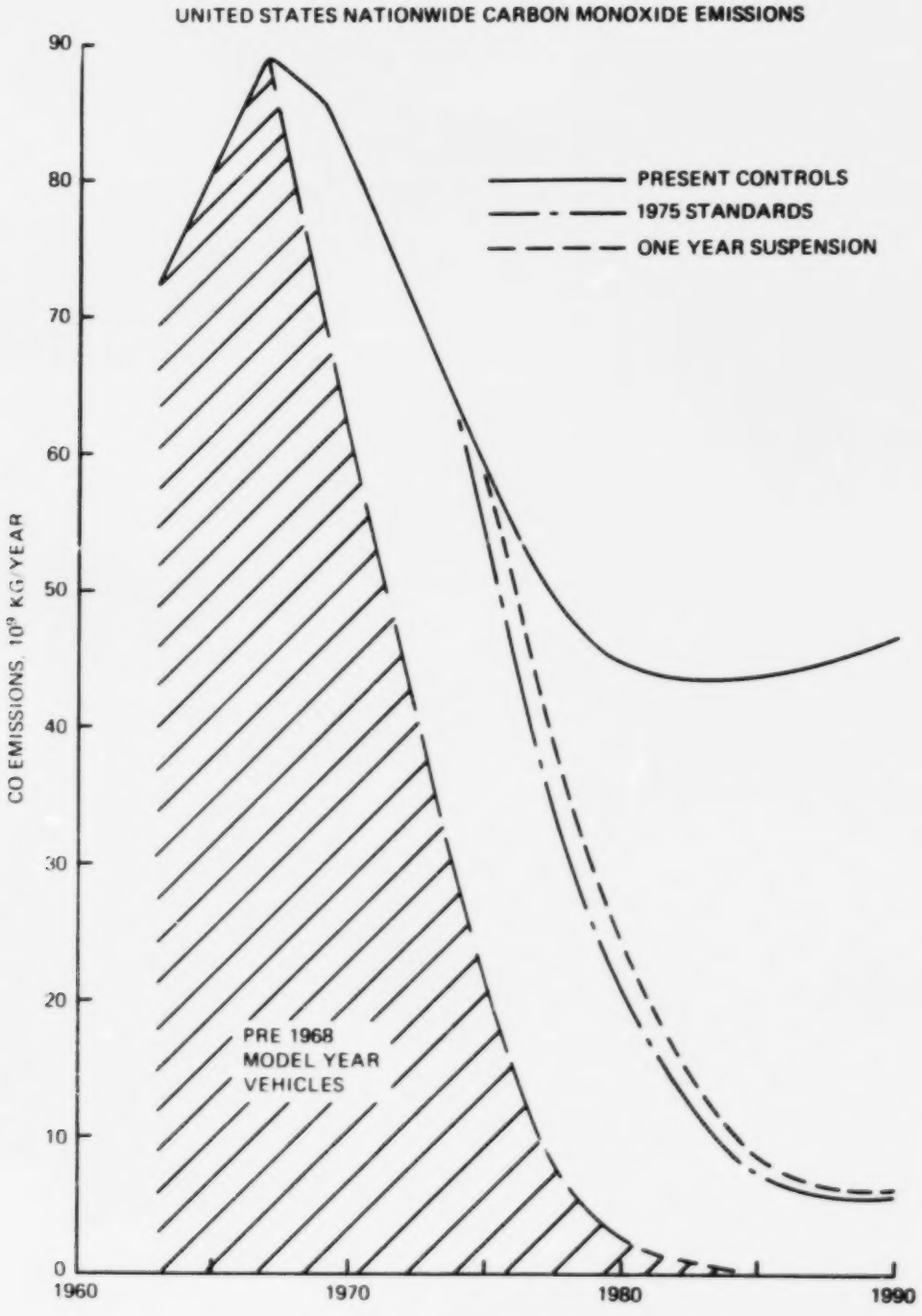

UNITED STATES NATIONWIDE CARBON MONOXIDE EMISSIONS
CO EMISSIONS, 10^9 KG/YEAR
90
80
70
60
50
40
30
20
10
0
1960
1970
1980
1990
PRESENT CONTROLS
1975 STANDARDS
ONE YEAR SUSPENSION
PRE 1968
MODEL YEAR
VEHICLES

Figure 7.2

is estimated from California Air Resources Board field surveillance data. Deterioration is not allowed for in post-1974 model year vehicles since no reliable estimate of its magnitude can now be made. Further details of the calculations are given in Appendix I.

For any given calendar year, the figures show total HC and CO emissions from (1) pre-1968 uncontrolled vehicles, (2) all vehicles, with the 1975 standards for HC and CO met in 1975 and subsequent model year vehicles, (3) all vehicles, with 1975 HC and CO standards met in 1976 and subsequent model year vehicles - a one-year suspension with the 1973 standard maintained, and (4) all vehicles with present standards only. It can be seen that the rate of decrease in emissions until about 1980 depends primarily on the retirement of pre-1968 uncontrolled vehicles from use. Thus the effect on total emissions of a one-year suspension with no additional interim standards appears to be small. The effect is not more significant because the emission reduction now required of model year 1974 vehicles, as compared with uncontrolled vehicles (80 percent for HC and 69 percent for CO), is already so substantial.

CONCLUDING STATEMENT

The Clean Air Amendments of 1970 have had the effect of accelerating progress by automobile manufacturers in emission control. Experimental vehicles have been built and operated that, at low mileage, exhibit levels of emissions less than those specified for 1975 model year vehicles. However, information establishing the sustained effectiveness, durability, and reliability of prototype 1975 vehicle systems during typical consumer mileage accumulation is not available. The Committee finds that the technology necessary to meet the requirements of the Clean Air Amendments for 1975 model year light-duty motor vehicles is not available at this time.

While there is no certainty today that any 1975 model year vehicles will meet the requirements of the Act, the status of development and rate of progress make it possible that the larger manufacturers will be able to produce vehicles that will qualify, provided that provisions are made for catalyst replacement and other maintenance, for averaging emissions of production vehicles, and for the general availability of fuel containing suitably low levels of catalyst poisons. Conversely, if the above provisions are not deemed acceptable by EPA, it appears most unlikely that any manufacturer will be able to meet the requirements of the Act. The Committee believes that the emission levels required in the Clean Air Amendments will not be achieved in service, in any event, unless regular, periodic maintenance of the emission-control system is required of the owner.

The estimated costs to the consumer of meeting the requirements of the Act for 1975 vehicles, in comparison with those for 1973 vehicles, include an increase in sticker price of about $200, 3 to 12 percent increase in fuel consumption, an increase in maintenance cost, and a deterioration in driveability of the car.

If enforcement of the requirements of the Act for 1975 vehicles were deferred for one year, the opportunity thus provided for further development and field testing would enable manufacturers to significantly improve the performance and reliability of vehicles equipped to meet the requirements in the hands of the customer.

The Committee finds that the technology necessary to meet 1976 standards in 1976 model year cars is not currently available. The technology of catalysts suitable for NO_x reduction is not nearly as advanced as that of oxidation catalysts. The level of current research and development on reduction catalysts for NO_x control is not commensurate with the importance of this problem.

9. FUTURE PLANS

The results of the investigations of the Committee to date indicate several areas in which work should be continued or intensified and several areas in which studies should be initiated.

The Committee will study in depth the technological feasibility of meeting the standards of the Clean Air Amendments applicable to emissions of oxides of nitrogen from light-duty vehicles manufactured during or after model year 1976. Investigation of the technological feasibility of meeting the standards applicable to 1975 model year vehicles will continue, with monitoring of new developments in this regard.

As emission systems are designed and put into production, the problems of inspection and maintenance will continue to be of interest to the Committee.

Extensive investigations will be initiated into the state of technology of alternate power systems and the potential they offer for emissions reductions over that of conventional engines. This study will consider cost, producibility, and maintainability of such alternate power sources.

Finally, an extensive study will be made of the consequences to the nation of achieving or failing to achieve the emissions standards of the 1970 Clean Air Amendments. This study will assist the Committee as it attempts to determine suitable interim emission levels as called for in the Work Statement of the Committee.

APPENDIX A

Committee on Motor Vehicle Emissions

E. L. Ginzton
Chairman
Varian Associates
Chairman

J. A. Hutcheson
Vice President
Westinghouse Electric
Corporation (retired)
Vice Chairman

Sidney W. Benson
Chairman
Department of Thermochemistry
and Kinetics
Stanford Research Institute

Robert W. Cairns
Deputy Assistant Secretary
for Science and Technology
U. S. Department of Commerce

Charles H. Elmendorf III
Assistant Vice President
American Telephone and
Telegraph Company

James A. Fay
Professor of Mechanical
Engineering
Department of Mechanical
Engineering
Massachusetts Institute of
Technology

Richard L. Garwin
IBM Fellow
Thomas J. Watson Research
Center

Irvin Glassman
Professor of Aerospace and
Mechanical Sciences
Department of Aerospace and
Mechanical Sciences
Princeton University

A. J. Haagen-Smit
Professor of Biochemistry
Division of Biology
California Institute of
Technology

Harold S. Johnston
Professor of Chemistry
Department of Chemistry
University of California

Arthur R. Kantrowitz
Director
AVCO-Everett Research
Laboratory

J. Ross Macdonald
Vice President of Corporate
Research and Engineering
Texas Instruments Incorporated

M. Eugene Merchant
Director of Research Planning
Cincinnati Milacron, Inc.

Glenn C. Williams
Professor of Chemical Engineering
Department of Chemical Engineering
Massachusetts Institute of
Technology

Staff

James E. A. John
Executive Director
Committee on Motor Vehicle Emissions
National Research Council

John E. Nolan
Assistant Executive Director
Committee on Motor Vehicle Emissions
National Research Council

Miss E. Gaspard-Michel
Administrative Assistant to the Chairmen
Committee on Motor Vehicle Emissions
National Research Council

Richard Barber
Legal Counsel
Committee on Motor Vehicle Emissions
National Research Council

APPENDIX B

Statement of Work

The Contractor shall conduct a many-faceted study of the technological feasibility of meeting the motor vehicle emission standards prescribed by the Administrator of the Environmental Protection Agency, as required by Section 202(b) of the Clean Air Act, as amended.

For the purposes of this study the term "technological feasibility" includes the ability within the automobile industry or elsewhere to

1. Design an engine, control system or device capable of meeting the statutory emission standards using fuels which are or could be available

2. Mass produce such an engine, control system or device

3. Maintain such an engine, control system or device so that it will continue to meet the statutory emission standards with safety for a period of five years or 50,000 miles of operation, whichever is shorter.

The study of technological feasibility as defined shall include a study emphasizing the technical aspects of the reported costs expected to be incurred in and the estimated time for the design, development and mass production of an engine, control system or device capable of meeting the statutory emission standards.

The study of technological feasibility shall include a study emphasizing the technical aspects of the reported estimates of extra cost incurred in maintaining such an engine, control system or device so that it will meet the statutory emission standards for a period of five years or 50,000 miles, whichever is shorter.

Should the Contractor conclude that the attainment of emission standards on the schedule provided by Section 202(b)(1) of the Clean Air Act is not technologically feasible, the Contractor shall specifically determine technologically feasible interim emission levels to assist the Administrator in exercising his responsibilities under Section 202(b)(5) of the Act.

APPENDIX C

Panels of Consultants

EMISSION STANDARDS

Arthur C. Stern
Environmental Science and Engineering
School of Public Health
University of North Carolina
Panel Chairman

Leslie A. Chambers
School of Public Health
University of Texas at Houston

James Fitzpatrick
Environmental Analysts, Inc.

John A. Maga
Air Resources Board
State of California

TESTING, INSPECTION AND MAINTENANCE OF VEHICLES

John N. Pattison
Civil Engineering Department
University of Cincinnati
Panel Chairman

Marian Chew
Chagrin Falls, Ohio

G. C. Hass
Air Resources Board
State of California

William Scott
Scott Research Laboratories

EMISSION CONTROL SYSTEMS
(for spark ignition internal combustion engines)

John B. Heywood
Department of Mechanical Engineering
Massachusetts Institute of Technology
Panel Chairman

J. A. Bolt
Department of Mechanical Engineering
University of Michigan

Ernest Jost
Materials and Electronic Controls Group
Texas Instruments, Inc.

Henry K. Newhall
Department of Mechanical Engineering
University of Wisconsin

William A. Sirignano
Guggenheim Laboratories
Department of Aerospace and Mechanical Sciences
Princeton University

Henry Wise
Stanford Research Institute

David Wulfhorst
Cummins Engine Co., Inc.

ALTERNATE POWER SOURCES

John Bjerklie
Consulting Engineer
Thermal Systems
Mechanical Technology, Inc.
Panel Chairman

Henry Korp
Engines, Fuels and Lubricants
Division
Southwest Research Institute

Charles Tobias
Department of Chemical
Engineering
University of California

David G. Wilson
Department of Mechanical
Engineering
Massachusetts Institute of
Technology

Clarence Zener
University Professor
Carnegie-Mellon University

DRIVEABILITY

King D. Bird
Vehicle Research Department
Cornell Aeronautical Labs

Leonard Segel
Highway Safety Research
Institute
University of Michigan

MANUFACTURING AND PRODUCIBILITY

Maurice Nelles
La Jolla, California
Panel Chairman

Donald Bartlett
A. T. Kearney & Company, Inc.

George D. Clayton
George D. Clayton and Associates

Merrill L. Ebner
College of Engineering
Boston University

Leroy H. Lindgren
Rath and Strong, Inc.

ATMOSPHERIC CHEMISTRY

Edward Stephens
Statewide Air Pollution
Research Center
University of California

Lowell Wayne
Los Angeles, California

APPENDIX D

List of Questions Sent to Foreign and Domestic Automobile Manufacturers; Recipients of Questionnaire and List of Attendees at CMVE meeting on October 25-27, 1971

1. Do you expect to meet the federal and California emission standards with 1975 model year vehicles? Explain any factors which qualify your answers.

2. What emission controls, and engine modifications which reduce emissions, do you expect to be using in your 1975 model year automobiles?

3. What are the best emissions results you have obtained with these control systems to date? Explain any factors you feel qualify these emissions measurements and their relation to the emission standards.

4. What are your engineering emissions goals for 1975 model experimental vehicles so that the production vehicles will meet the requirements of the 1970 Clean Air Act Amendments?

   Explain how possible requirements that
   (a) assembly line vehicles pass a short emissions test,
   (b) a certain fraction of assembly line vehicles pass the full federal emissions test,
   (c) a certain fraction of vehicles in customer use pass the full federal emissions test,

   affect these engineering emission goals and hence affect your ability to meet the 1975 emissions standards.

5. What major development problems do you have to solve before you can meet these experimental vehicle emission goals?

6. At what date do you expect to meet these experimental vehicle emission goals?

7. What changes in vehicle performance, driving characteristics, and fuel consumption do you anticipate with these systems in your 1975 model year production vehicles?

8. If you do not expect to meet the 1975 Federal Emission Standards with 1975 model year vehicles, what emission levels do you anticipate achieving with production vehicles?

9. Do your 1975 model year emission control systems have the potential with further development of meeting the 1976 emission standards? If not, what emissions reduction from 1975 levels do you anticipate achieving?

10. What is the degree of statistical reproducibility of the test procedure results as applied to your 1975-type cars? Explain.
    (a) What combination of maintenance and inspection will be required for your 1975 vehicles in order to meet federal requirements for 1975 used vehicles? What inspection systems will be needed, if any?
    (b) What do you expect the average annual maintenance and inspection costs will be? If there are compensating savings in fuel or other costs, show these. Explain your reply.

11. Have you the capability of producing automobiles to meet the federal 1975 model requirements? If not how must your capabilities be augmented?

12. Are you executing plans to acquire capabilities and items from others to enable you to produce vehicles to meet the 1975 requirements? What are the major items you must acquire, including machinery?

13. What is the maximum decrease in HC, CO and NO_x exhaust content you could achieve with the use of your normal production capabilities during the next three years? Base decrease on 1960 emissions.

14. Provide PERT, GANTT or similar charts indicating plans for meeting the 1975 emission standards. The end point may be the time you have chosen to meet the 1975 standards. Events and times should be labeled.

15. What advantage would there be to you if the date 1975 standards would be effective were delayed one year?

16. Approximately, what will the extra cost be to prepare to produce medium weight vehicles to meet the 1975 standards? What are the chief items of cost?

17. What will the range of additional costs to the ultimate customer be for meeting the 1975 requirements over the 1970 requirements, if you find it necessary to meet the requirement for the 1975 model? For the 1976 model?

18. Construct the following curves using your best available data and judgment.
    (a) Cost to customer $ vs % of CO eliminated (based on 1960 emissions including crank case and evaporation).

(b) Cost to customer $ vs % of HC eliminated (based on 1960 emissions including crank case and evaporation).
(c) Cost to customer $ vs % of NO_x eliminated (based on 1960 emissions including crank case and evaporation).
(d) Cost to customer $ vs equal % of HC and NO_x eliminated (based on 1960 emissions including crank case and evaporation).
(e) Cost to customer $ vs equal % of HC, CO, NO_x eliminated (based on 1970 emissions).
(f) Any other similar type curve which will show the cost to the customer for various amounts of pollution eliminated.

19. Will warranty costs be increased to cover the guarantees required by the Amendment? If increased, how much?

20. Do you expect to meet the Federal Emission Standards for 1976 model year vehicles? Explain any factors which qualify your answer.

21. What additional or alternative control systems are you investigating for spark-ignition engines to meet the 1976 model year emission standards which promise greater NO_x emission control?

22. What are the best emissions results you have obtained with the different systems you are developing to meet the 1976 emission standards? List any factors you feel qualify these emission measurements and their relation to the emission standards.

23. What are the major development problems to be solved for each of these systems before you meet your 1976 emission goals with these different approaches?

24. How much time do you anticipate you will require to resolve these development problems for the 1976 Federal Emission Standards?

25. What changes in vehicle performance penalties, driving characteristics, and fuel consumption do you anticipate for the different 1976 emission control approaches you are considering?

26. If you do not expect to meet the 1976 emission standards for 1976 model year vehicles, what emission levels do you anticipate achieving with production vehicles?

27. (a) Do you anticipate using the Wankel rotating combustion engine in any of your 1975 or 1976 production vehicles?
(b) If you are evaluating Wankel engines for possible future production, what are the best emissions results you have achieved to date, and with what additional emissions controls?

(c) Do you feel the Wankel engine has any special emissions advantages for achieving emissions levels that would satisfy the 1975 or 1976 emission standards?
(d) What is the magnitude of your research and development effort to reduce emissions from Wankel engine?

28. (a) Do you anticipate using the stratified charge engine in any of your 1976 production vehicles?
(b) Do you feel the stratified charge engine (open chamber type, or divided or precombustion chamber type) has any special advantages for achieving emissions levels that would satisfy the 1975 or 1976 emission standards?
(c) What is your estimate of the potential for emissions reduction with the stratified charge engine when used with other emission controls?
(d) What are the major development problems to be overcome with the stratified charge engine?
(e) What is the magnitude of your research and development effort on stratified charge engines?
(f) What is your estimate of the earliest date at which the stratified charge engine could be used in a substantial fraction of your production vehicles?

29. (a) Do you feel that the gas turbine is a promising automotive power plant? List its advantages and disadvantages in relation to current engines.
(b) What is your estimate of the low emissions potential of the automotive gas turbine?
(c) What are the major development problems to be overcome before the automotive gas turbine is a viable mass production engine?
(d) What is the magnitude of your research and development effort on automotive gas turbines?
(e) What is your estimate of the earliest date at which the gas turbine could be used in a substantial fraction of your production automobiles?

30. Which of all the emission control approaches you have investigated (or other approaches) is most attractive with respect to vehicle performance, fuel economy, and cost, and which with further development has the potential of meeting the 1976 emission standards with production vehicles at some time during the period 1977-1982?

31. If this approach is different from your basic 1975 or 1976 model year control systems, what major development problems have to be overcome to make these alternative approaches attractive for production vehicles, and what is your estimate of the time and effort which would be required?

Recipients of Questionnaire

Domestic Manufacturers

American Motors
14250 Plymouth Road
Detroit, Michigan
Attn: John F. Adamson
Vice President - Engineering
and Research

Chrysler Corporation
Materials Engineering
Engineering and Research Office
12800 Oakland Avenue
Detroit, Michigan
Attn: Charles M. Heinen
Executive Engineer

Ford Motor Company
Automotive Emissions Office
Engineering Staff
The American Road
Dearborn, Michigan
Attn: Donald A. Jensen
Director

General Motors Corporation
General Motors Technical Center
Warren, Michigan
Attn: Ernest S. Starkman
Vice President
Environmental Activities
Staff

International Harvester Company
Motor Truck Engineering Department
P. O. Box 1109
Fort Wayne, Indiana
Attn: Mark Sherbinski
Staff Engineer
Vehicle Emission

Jeep Corporation
940 North Cove Boulevard
Toledo, Ohio
Attn: Frederick A. Stewart
Vice President,
Engineering

U. S. Army Tank-Automotive Command
Headquarters
Warren, Michigan
Attn: Ernest Petrick
Chief Scientist

White Motor Corporation
Advanced Products Division
3201 Lomita Boulevard
Torrance, California
Attn: John McLean

Foreign Manufacturers

Alfa Romeo - S.p.A.
Via Gattanelata 45
20149 Milano, Italy
Attn: O. Satta
General Manager

Alfa Romeo
215 Douglas Street
El Segundo, California
Attn: Michael Pokorny
Service Manager

Audi
NSU Motorenwerke
General Series Design and
Development
Aktiengesselschaft
7107 Neckarsulm
Germany
Attn: P. A. Praxl

Bayerische Motoren Werke A.G.
8 Munchen 13
Lerchenauer Str. 76
W. Germany
Attn: W. Stork

British Leyland Motors, Inc.
600 Willow Tree Road
Leonia, New Jersey
Attn: G. W. Gardner

Daimler-Benz A.G.
Stuttgart-Underturkheim
Germany
Attn: The President

Mercedes Benz
815 Connecticut Avenue, N.W.
Washington, D. C.
Attn: Jerry Sanosky

FIAT S.p.A.
375 Park Avenue
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Attn: Alberto Negro
Liaison Engineer
Technical Development

FIAT S.p.A.
Strada del Drosso 145
10135 Torino, Italy
Attn: Carlo Pollone
Direzione ricerca

Fuji Heavy Industries Ltd.
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Attn: Nobuko Sakata
Managing Director

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Attn: Yuji Satoh
President

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Attn: K. Hirota
Machinery Division

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Manager, Detroit Liaison
Office

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Attn: Yasuo Kaneko
Chief of Research Section

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Yokohama, Japan
Attn: Hiroshi Takahashi
Director and Manager,
Design Department

Nissan Motor Corporation in U.S.A.
137 East Alondra Boulevard
Gardena, California
Attn: Noboru Hayakawa
Factory Representative

Nissan Motor Corporation of the
U.S.A.
400 County Avenue
Secaucus, New Jersey
Attn: Takashi Yukawa
Chief Representative

Peugeot, Inc.
300 Keller Road
Clifton, New Jersey
Attn: Michael Rousman
Engineering Advisor

Porsche Audi
600 Sylvan Avenue
Englewood Cliffs, New Jersey
Attn: Normann Roethlein
Product Planning Department

Renault, Inc.
100 Sylvan Avenue
Englewood Cliffs, New Jersey
Attn: François Louis
National Manager, Service
and Parts Division

Regie Nationale des Usines Renault
10, Avenue Emile Zola
92 Billancourt, France
Attn: Pierre Vernay
Engineer, Research for
Export Department

SAAB U.S.A., Inc.
100 Waterfront Street
New Haven, Connecticut
Attn: Don Tayler
President

SAAB-Scania Automotive Group
S-461 01
Trollhattan, Sweden
Attn: Henrik Gustavsson
Technical Director

Toyo Kogyo Company, Ltd.
6047 Suchu-Machi, Aki-gun
Hiroshima, Japan
Attn: Eisuke Niguma
Manager, Export Vehicle
Engineering Department

Toyota Motor Company, Ltd.
1 Toyota-Cho, Toyota-Shi
Aichi-Ken, Japan
Attn: Masaaki Noguchi
Executive Managing Director

Toyota Motor Sales U.S.A., Inc.
2055 W. 190th Street
P. O. Box 2991
Torrance, California
Attn: Dan N. Koda
Manager, Technical Services

VW of America, Inc.
Product Development Engineering
Englewood Cliffs, New Jersey
Attn: Bernard R. Patok

VW of America, Inc.
818 Sylvan Avenue
Englewood Cliffs, New Jersey
Attn: G. Stobeck
Product Planning Manager

AB Volvo
Car Engine Department
S-405 08
Gothenberg, Sweden
Attn: G. Zackrisson
Chief Engineer

Volvo, Inc.
Rockleigh, New Jersey
Attn: Charles J. Simerlein
Special Assistant,
Federal Regulations

Responses were received from all recipients of questionnaires.

Attendees at CMVE Meeting, October 25-27, 1971

October 25

1:00 - 2:30 General Motors Corporation

F. W. Bowditch
Director of Automotive Emissions Control
W. C. Chapman
International Government Relations Staff
David Milne
Manufacturing Development Staff
J. C. Salrin
Financial Staff
Ernest S. Starkman
Vice President

2:30 - 4:00 Toyota Motor Company, Ltd.

Keitaro Nakajima
Director, General Manager
Factory Representative Office
Kuniyasu Onoda
Staff Engineer
Factory Representative Office
Hidemasa Takagi
Staff Engineer
Factory Representative Office

8:00 - 9:00 Renault, Inc.

François Louis
Manager

October 26

9:00 - 10:30 International Harvester Company

Rodger Ringham
Vice President of Engineering
Mark Sherbinsky
Staff Engineer, Vehicle Emissions

10:30 - 12:00 Chrysler Corporation

Charles M. Heinen
Executive Engineer, Materials Engineering
George Lacey
Chief, Emissions Control
S. L. Terry
Vice President for Environmental and Safety Relations

1:00 - 2:30 American Motors

John F. Adamson
Vice President, Engineering and Research
Carl E. Burke
Assistant Chief Engineer of Advanced Engineering and Research
Albert R. Ebi
Executive Director, Product Planning
Daniel L. Hittler
Manager, Development Department, Engineering and Research
Robert A. Petersen
Chief Engineer of Advanced Engineering and Research

2:30 - 4:00 U. S. Army Tank-Automotive Command

Wayne Anderson
Chief, Propulsion Systems Division
Bruce Hildebrand
Chief, Environmental Control Office
U. S. Army Materiel Command
Ernest Petrick
Chief Scientist

4:00 - 5:30 Nissan Motor Company, Ltd.

L. Raymond
Engineering Consultant
Y. Tamuchi
Engineering Representative
T. Tanuma
Senior Engineer
T. Yukawa
Chief Representative

8:00 - 9:00 Mitsubishi Motors Corporation

Y. Kiso
General Manager
Detroit Liaison Office
Hachiro Ursumi
Project Manager
Emissions Control Systems
K. Wada
Engineer

October 27

9:00 - 10:30 Volkswagen

Karl H. Neumann
Staff Engineer, Emissions Control
Volkswagenwerke, A. G.
Gerhard Reichel
Attorney, Legal Department
Hans Weisbarth
Technical Development Liaison Engineer
Volkswagen of America, Inc.

10:30 - 12:00 Ford Motor Company

G. C. Gagliardi
Principal, Research Engineering
Product Division Group
D. A. Jensen
Director, Automotive Emissions Office
J. M. MacNee
Office of the General Counsel
Herbert L. Misch
Vice President, Engineering and
Manufacturing
H. A. Poling
Comptroller, Product Development
R. Ronzi
Emission Planning Association
R. E. Taylor
Chief Engineer
Engineering and Foundry Division

1:00 - 2:30 Volvo, Inc.

Douglas Jarman
Vice President
National Sales, U. S.
Magnus Straakander
Engine Division

APPENDIX E

Letter Requesting Information from Public

The Clean Air Act Amendments of 1970 (PL 91-604) call for the National Academy of Sciences to conduct "a comprehensive study and investigation of the technological feasibility of meeting" the auto-emission standard prescribed by the law. These standards, in general, are designed to achieve a reduction compared with 1970 of 90 percent by 1975 in automobile emissions of carbon monoxide and hydrocarbons and by 1976 in oxides of nitrogen.

In its study the Academy is concerned solely with the "technological feasibility" of meeting these standards by the specified model years. Intensive scientific and engineering work is being conducted by a special Academy committee. The most immediate concern of the committee is with the 1975 standards for carbon monoxide and hydrocarbons, since in these respects the automobile manufacturers are entitled by law to seek a suspension in the effective date of one year on or after January 1, 1972, from the Environmental Protection Agency. In acting on such a request the Administrator is obligated to consider the Academy's findings with respect to technological feasibility.

In order to assist it in its work and to elicit as wide as possible a range of technical opinion, the committee invites organizations and others possessing technical competence to submit in writing any materials or information directly relevant to the "technological feasibility" of meeting the 1975 Clean Air Act Auto Emissions Standards. It should be emphasized that the following matters are beyond the scope of the NAS present undertaking: (1) public health consequences of air pollution, (2) emissions other than carbon monoxide and hydrocarbons and, (3) new power sources which cannot be mass produced by 1975.

All materials submitted in response to this invitation must be received by the Academy not later than October 20, 1971.

Submissions should be addressed to

National Academy of Sciences
Committee on Motor Vehicle Emissions
Attn: Public Comments
Washington, D. C. 20418

APPENDIX F

Emissions at Low Mileage from Each
Automobile Manufacturer's Best Vehicle+

Manufacturer	Emissions, grams/mile*		
	HC	CO	NO_x
United States			
A	0.21	3.5	1.2
B	0.15	2.4	2.1
C	0.13	1.9	1.3
D	0.31	2.3	1.7
E	0.24	3.7	4.5
Foreign**			
F	0.11	3.7	2.2
G	0.3	3.0	0.6
H	0.26	3.1	1.1
I	0.4	4.7	2.1
J	0.25	3.0	2.5
K	0.26	2.4	1.0
L	0.6	3.5	2.3
M	0.62	5.7	2.2
N	0.2	4.4	-
O	0.63	5.8	-
P	0.3	3.1	1.9
Q	0.1	2.5	1.0
R	0.3	3.2	1.5

+ As of October 15, 1971. Usually average of several tests. 1975 CVS-CH test procedure used except for manufacturers A, D, N, O, R, which employed the 1972 CVS-C test procedure.

** Some of these results are with research systems at very low mileage which do not have mass production potential in their current form.

* Data obtained from visits of Emission Control Systems Panel to manufacturers and manufacturers' responses to Committee questionnaire dated September 27, 1971.

APPENDIX G

Emissions as Function of Miles for Durability Tests on Different Catalysts and Vehicles

Catalyst		Vehicle	Mileage	Emissions, gram/mile[a] HC	CO
Catalyst manufacturer A, platinum on pellets	(i)	Current production vehicle. Lean carburetion and air pump. No EGR.	0	0.19	1.5
			8,000	0.54	2.4
			16,500	0.42	1.2
			21,933	0.66	2.9
Catalyst manufacturer B, platinum on monolith	(ii)	Current production vehicle. Lean carburetion and air pump. No EGR	50,000	0.7	3.8
	(iii)	Current production vehicle. Lean carburetion and air pump. No EGR	0	0.04	2.3
			4,000	0.18	4.4
			44,000	0.45	9.6
	(iv)	Prototype 1975 system including rich carburetion, air pump and EGR.	0	0.4	4.0
			4,000	0.8	8.0
			10,000	1.2	14.0
			15,000	0.8	12.5
			20,000	0.9	17.0
Catalyst manufacturer C, base metal on pellets	(v)	Prototype 1975 system.	0	0.32	5.5
			4,000	0.36	4.6
			8,000	0.26	3.5
			12,000	0.26	4.0
			16,000	0.35	5.5
			20,000	0.39	4.5
			24,000	0.35	5.8
			28,000	0.50	6.5
			32,000	0.34	5.0

---

a. 1972 CVS-CH test procedure used except for vehicle (v) where 1972 CVS-CH was used.

Notes:

1. Vehicles (i) (ii) and (v) show fluctuations in emissions due to variation in emissions during engine start up at the beginning of the test and changes in carburetor setting, as well as catalyst deterioration.

2. Vehicles (iii), (iii) and (iv) used similar catalysts. Vehicles (iii) and (iii) are carbureted lean and did not use EGR to reduce NO_x emissions below 1975 standards of 3 g/mile. Vehicle (iv) has EGR and richer carburetor setting so HC and CO emissions in exhaust gas entering the converter are substantially higher. Emissions at converter exit are higher and deterioration in control is greater.

3. Tests on vehicles (i) and (iii) were run by catalyst manufacturer; tests on vehicles (iii), (iv) and (v) were run by automobile manufacturers.

4. Data received by Committee up to December 2, 1971.

APPENDIX B

Panel Estimate of Sticker Prices of Likely Emissions Hardware

Model Year	Configuration	Value[1] Added	Tooling[2] Amortization	Dealer[3] Margin	Profit[4]	List Price	Excise[5] Tax	Sticker Price
1966	PCV-Crank Case	1.90		.66	.29	2.85	.15	3.00
1968	Fuel Evaporation Control System	9.07	.50	3.30	1.43	14.30	.75	15.00
								(18.00)
1970	Ignition Timing	.61	.02	.22	.10	.95	.05	1.00
	Carburetor A/F Ratio	.61	.02	.22	.10	.95	.05	1.00
	Compression Ratio	1.24	.03	.44	.19	1.90	.10	2.00
	Transmission Control System	2.49	.05	.88	.38	3.80	.20	4.00
								(8.00)
1971 1972	Anti-Dieseling Solenoid	3.07	.10	1.10	.48	4.75	.25	5.00
	Thermostatic Air Valve	2.49	.05	.88	.38	3.80	.20	4.00
	Choke Heat Bypass	2.74	.05	.97	.42	4.18	.22	4.40
	Assembly Line Tests for California (1/10 Volume)	.18	.20	.13	.06	.57	.03	.60
								(14.00)

Model Year	Configuration	Value[1] Added	Tooling[2] Amortization	Dealer[3] Margin	Profit[4]	List Price	Excise[5] Tax	Sticker Price
1973	EGR (11-17)	5.48	.82	2.20	.95	9.45	.50	10.00
	Air Pump - Air Injection System	27.16	1.80	10.03	4.33	43.32	2.28	45.60
	Induction Hardened Valve Seats	.72	.55	.44	.19	1.90	.10	2.00
	Spark Advance Control	.48	.15	.22	.10	.95	.05	1.00
	Transmission Changes (Some Models)	.63	-	.22	.10	.95	.05	1.00
	Quality Audit Assembly Line for California (1/10 Volume)	.22	.02	.09	.04	.38	.02	.40
								(60.00)
1974	Precision Cams -- Bores - Pistons	2.44	.10	.88	.38	3.80	.20	4.00
	Induction Hardened Valve Seat V-8	.72	.55	.44	.19	1.90	.10	2.00
	Some Proportional EGR (10% @ 52.00)	3.21	.10	1.14	.49	4.94	.26	5.20
	Pretest Engines -- Emissions	1.80	.10	.66	.29	2.85	.15	3.00
	Catalytic Converter System for California (1/10 Volume)	4.02	.06	1.40	.61	6.09	.31	6.40
								(20.60)

Model Year	Configuration	Value[1] Added	Tooling[2] Amortization	Dealer[3] Margin	Profit[4]	List Price	Excise[5] Tax	Sticker Price
1975	Proportional EGR	29.71	-	10.30	4.45	44.46	2.34	46.80
	New Design Carburetor with Altitude Compensation	7.52	2.00	3.30	1.43	14.25	.75	15.00
	Advanced Air Injection Control	24.90	.50	8.80	3.80	38.00	2.00	40.00
	Air/fuel Preheater	2.87	.30	1.10	.48	4.75	.25	5.00
	Electric Choke (element)	2.67	.50	1.10	.48	4.75	.25	5.00
	Electronic Distributor (Pointless)	4.35	2.00	2.20	.95	9.50	.50	10.00
	Improved Timing Control $\pm 1^{o}$	1.40	.50	.66	.29	2.85	.15	3.00
	Catalytic (Oxidizing) Converter	18.66	4.00	7.92	3.42	34.20	1.80	36.00
	Pellet Charge 6 lbs @ $2.00 lb.	12.00	1.70	4.75	2.05	20.50	1.10	21.60
	Cooling System Changes	1.17	.10	.44	.19	1.90	.10	2.00
	Improved Underhood Materials	.63	-	.22	.10	.95	.05	1.00
	Body Revisions	.67	.60	.44	.19	1.90	.10	2.00

Model Year	Configuration	Value[1] Added	Tooling[2] Amortization	Dealer[3] Margin	Profit[4]	List Price	Excise[5] Tax	Sticker Price
1975	Assembly Line Changes	.08	.50	.22	.10	.90	.05	1.00
	End of Line Test Go - No Go	1.85	.05	.66	.29	2.85	.15	3.00
	Quality Emission Test	1.22	.05	.44	.19	1.90	.10	2.00
								(193.40)

Notes to Appendix

1. Either value added or hardware cost, including material, labor, overhead and general administrative costs.

2. Tooling and equipment amortized over three years.

3. As 22% of selling price.

4. As 10% of list price.

5. As 5% of sticker price.

APPENDIX I

Data Used to Calculate Emissions from Light Duty Motor Vehicles

Tables I1 to I4 summarize the data used to calculate emissions as a function of calendar year for Figures 7.1 and 7.2.

Table I-1

Percent of Annual Vehicle Miles Traveled by Different Age Groups

Vehicle Age (years)	Percent of total annual vehicle miles
1	15.73
2	13.64
3	12.02
4	10.07
5	9.35
6	8.18
7	7.5
8	6.6
9	5.3
10	4.3
11	2.8
12	1.7
13	0.8
14	0.4
more than 14	1.6

Source: United States Department of Commerce

Table 1-2

Assumed New Car Emissions as Function of Model Year

Model Year	EMISSIONS, GRAMS/MILE*			
	Hydrocarbons			Carbon Monoxide
	Exhaust	Blowby	Evaporation	
pre-1963	17	4.08	2.77	125
1963-1967	17	0.82	2.77	125
1968-1969	7.0	0	2.77	71
1970-1971	4.0	0	2.77	47
1972-1974	3.4	0	0.14	39
1975-1990	0.43	0	0.14	4.7

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*Corresponds to CVS-C (1972) test procedure.

Source for conversion factors: Environmental Protection Agency.

Since test procedure corresponds to summer, annual emissions are obtained by multiplying g/mile values in above table by 1.12 (urban) and 1.0 (rural) for HC, and by 1.085 (urban) and 0.92 (rural) for CO.

Table 1-4

Annual Total Light-Duty Vehicle-Miles of Travel In United States

Year	Total Miles (10^9)	Percent	
		Urban	Rural*
1963	655.5	0.50	0.50
1970	898.5	0.53	0.47
1980	1208.0	0.57	0.43
1990	1437.0	0.61	0.39

Source: United States Department of Transportation

*To allow for higher average speed in rural driving, emissions in grams/rural mile are values given in Table G-2 multiplied by 0.552 for HC and 0.466 for CO.

Table I-3

Examples of Average Vehicle Emissions Deterioration Factors

Vehicle Age (years)	Deterioration Factor*	
	HC	CO
1	1.063	1.055
5	1.252	1.195
10	1.296	1.201
15	1.302	1.203

*Based on California Air Resources Board field surveillance data. Deterioration above the standards in 1975 and later model year vehicles is not allowed for.